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In this issue

AMERICAN WATER WORKS ASSOCIATION
INCORPORATED

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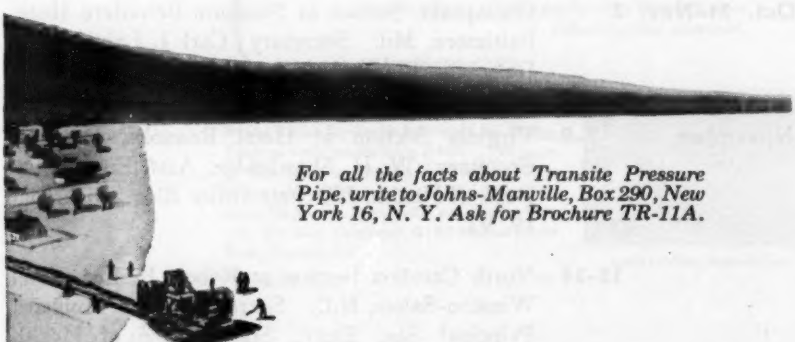

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COMING MEETINGS

October **14–17**—Southwest Section at Hotel Texas, Fort Worth, Tex. Secretary: Leslie A. Jackson, Mgr.-Engr., Municipal Water Works, Robinson Memorial Auditorium, Little Rock, Ark.

23–26—California Section at Fairmont Hotel, San Francisco. Acting Secretary: Lee Streicher, Chief Chemist, Metropolitan Water Dist. of Southern California, Box 38, LaVerne, Calif.

25–27—New Jersey Section at Madison Hotel, Atlantic City. Secretary: C. B. Tygert, Wallace & Tiernan Co., Box 178, Newark 1, N.J.

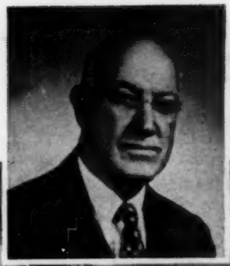
25–27—Iowa Section at Hotel Julian, Dubuque. Secretary: H. V. Pedersen, Supt. of Water Works, Municipal Bldg., Marshalltown, Iowa.

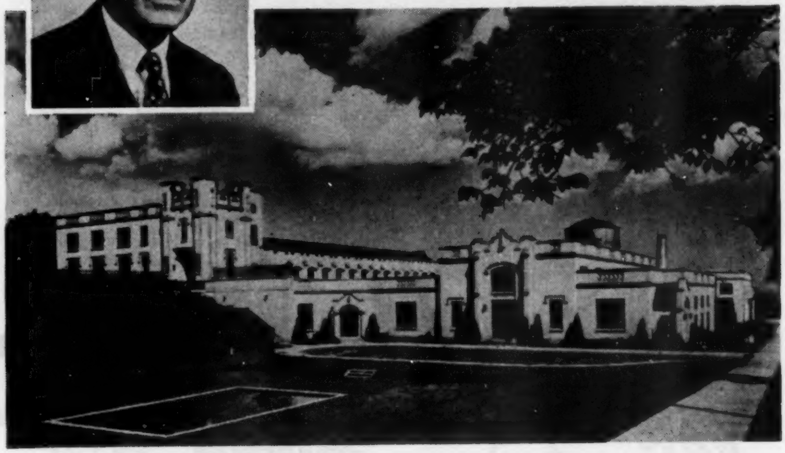
28–31—Florida Section at Sheraton Plaza Hotel, Daytona Beach. Secretary: Marvin R. Boyce, 504 Pennsylvania Ave., Clearwater, Fla. (Joint meeting with Florida Sewage and Industrial Wastes Association.)

Oct. 31–Nov. 2—Chesapeake Section at Sheraton-Belvedere Hotel, Baltimore, Md. Secretary: Carl J. Lauter, 5902 Dalecarlia Pl., N.W., Washington 16, D.C.

November **7–9**—Virginia Section at Hotel Roanoke, Roanoke. Secretary: W. H. Shewbridge, Asst. Engr., State Dept. of Health, 708 State Office Bldg., Richmond 19, Va.

12–14—North Carolina Section at Robert E. Lee Hotel, Winston-Salem, N.C. Secretary: E. C. Hubbard, Principal San. Engr., State Board of Health, Raleigh, N.C.





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Journal
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Studies on the Removal of Radioactive Contaminants From Water

By Conrad P. Straub, Roy J. Morton and Oliver R. Placak

A contribution to the Journal by Conrad P. Straub, San. Engr., U.S. Public Health Service, Roy J. Morton, Leader, Radioactive Waste Disposal Research and Development Section, and Oliver R. Placak, Senior Scientist, U.S. Public Health Service, all serving with the Health Physics Div., Oak Ridge National Lab., Oak Ridge, Tenn. *The work described in this report was performed under Contract No. W-7405-Eng-26 for the Atomic Energy Commission.*

THE broad cooperative program of the Waste Disposal Research and Development Section, Health Physics Div., Oak Ridge National Laboratory, has been described briefly in two recent articles (1, 2). This presentation will be restricted to a report of the investigations that have been made in the removal of single radioisotopes and of combinations of radioisotopes from waste solutions by conventional water treatment techniques. Such modified procedures as phosphate coagulation and clay adsorption were used for the removal of radioisotopes. Included also are the experimental results obtained in the operation of a water treatment pilot plant for the removal of radioactive materials.

Laboratory Studies

To obtain information on the effectiveness of coagulation in the removal of a series of individual radioisotopes, standardized jar test procedures were employed (3). Specific concentrations of coagulating chemicals, turbidity and radioisotopes were added to a given quantity of water, and the mixtures were subjected to a 3-minute rapid mix and 27-minute slow mix. After mixing, the floc was allowed to settle for 30 minutes. Samples of the supernatant liquor and sludge were extracted, placed in aluminum counting dishes, dried under infrared heat lamps and counted in a Geiger-Mueller end-window counter.

The results of the laboratory studies may be grouped in at least two ways: [1] according to the radioisotope studied * and [2] according to the process employed. The latter grouping will be used because members of the water works profession generally are more interested in processes. A total of 53 series, each of five jar tests, were made; 7 series of tests in the study of Ce^{144}, 8 of Y^{91}, 10 of Sr^{89}, 13 of I^{131}, 10 of P^{32} and 5 of iodine dissolver solution (mixed fission products waste).

Removal by Turbidity

Most surface waters contain variable amounts of turbidity, usually in the form of fine clay or silt particles. Some radioisotopes, either through adsorption, ion exchange or a combination of both, will be removed by this turbidity. If the process is primarily one of adsorption, it may be assumed that the process will follow the Freundlich-type reaction, which is expressed empirically by the exponential relationship:

$$\frac{x}{M} = k\,C^n$$

in which:

$\frac{x}{M}$ is the adsorption per unit weight of adsorbent,

x equals C_0 minus C, which is the amount of material adsorbed, or the initial concentration of adsorbable material minus final concentration of adsorbable material,

C is the concentration remaining (non-adsorbed fraction),

k and n are constants, depending upon the materials investigated.

This expression is modified here by denoting x, C_0 and C as the concentration of activity (or radioisotope) in terms of the counts per minute per milliliter (cpm. per ml.) and by expressing

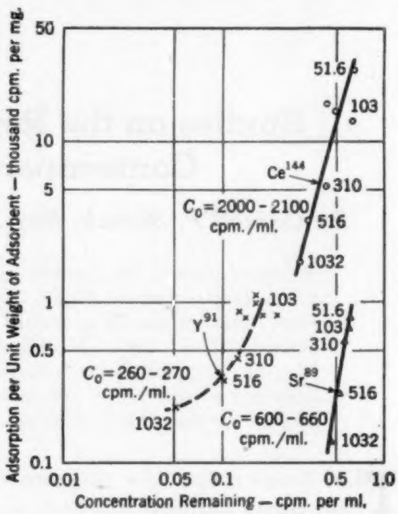

Fig. 1. Log–Log Plot of Freundlich-Type Isotherms

The removals of Ce^{144}, Y^{91} and Sr^{89} from solution by clay turbidity are plotted. C_0 is the initial concentration of adsorbable material.

M as the milligram per liter (ppm.) of adsorbent (turbidity) added. In the use of this modified expression, the values x, C_0 and C represent only the radioactive fraction, as no consideration is given to the stable isotopes present that may be adsorbed. The reported $\frac{x}{M}$ ratios may be considerably lower, therefore, than if an evaluation were made

* The individual isotopes treated were in the chemical form listed in Catalog and Price List No. 4, Isotopes Div., U.S. Atomic Energy Commission, Oak Ridge, Tenn. (March 1951). P^{32} was initially present as phosphate; Ce^{144}, Y^{91}, Sr^{89} and Ru^{106} as chlorides; I^{131} as iodide; Zr^{95} and Nb^{95} as oxalates. Mixed fission products wastes contain all elements produced in the fission process.

of the total adsorbable concentration, radioactive and stable. Freundlich-type isotherms for Ce^{144}, Sr^{89} and Y^{91} are shown in Fig. 1, and proportional removals for various turbidity dosages are shown in Fig. 2 for Ce^{144}, Y^{91}, Sr^{89} and iodine dissolver solution. In these studies, a clay soil of local origin was prepared as a slurry and was added to tap water to produce the desired turbidities. The results illustrated in Fig. 1 and 2 are based on removals following 3-minute rapid mixing, 27-minute slow mixing and 30-minute settling.

More recent studies (4) have shown that the rate of mix (rapid or slow) affects removal rates greatly. The addition of 100 ppm. of clay to a solution containing Ce^{144} followed by 5-minute rapid and 25-minute slow mix showed a removal of 25.2 per cent by the clay; with 30-minute rapid and no slow mix, a removal of 92.8 per cent. The addition of 100 ppm. of clay to a solution containing Y^{91} produced similar results. With slow mix, only 38.8 per cent of the Y^{91} was removed; with rapid mix, removal was increased to 93.4 per cent. The effect of rapid or slow mix may have been more pronounced in the local clay slurry because it was of a size that settled out during slow mixing, thereby reducing the number of surfaces in contact with the radioactive solution. Rapid mixing overcame this and resulted in much better removals.

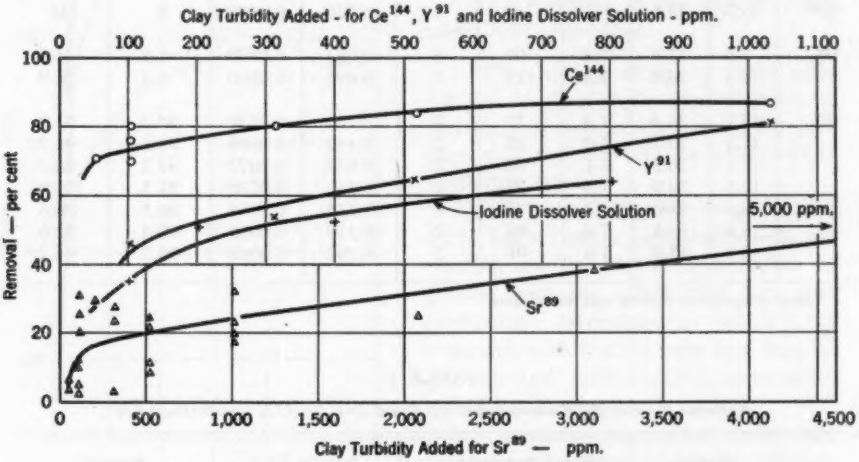

Fig. 2. Removal of Ce^{144}, Y^{91}, Sr^{89} and Iodine Dissolver Solution

The proportions are shown of Ce^{144}, Y^{91}, Sr^{89} and iodine dissolver solution removed from solution by adding various amounts of local clay turbidity. The lower abscissal scale applies only to Sr^{89} and the upper one to the other three materials.

The data plotted in Fig. 1 and 2 show that wide differences in removal may be encountered, dependent upon the particular isotope involved. Subsequent studies have further shown that the particular adsorbent used also has a major effect on removal. Extreme caution should therefore be exercised in interpreting statements that have been

TABLE 1

Removal of Specific Radioisotopes by Alum and NaOH Coagulation (3)

Radio-isotope	Dosage		Final Characteristics			Activity Total		Removals	
	Alum	NaOH	pH	Alkalinity	Turbidity	Initial	Final*	Coagulation and Settling	Coagulation, Settling and Centrifuging
	ppm.			*ppm.*		*million cpm.*		*per cent*	
Ce^{144}	25.7	45.6	7.2	74	4	1.610	0.1700	82.6	89.4
Y^{91}	25.7	45.6	6.6	70	6	0.190	0.2000	0	0
	25.7	15.2	6.8	26	4	0.028	0.0180	32.1	35.7
Sr^{89}	25.7	45.6	6.7	32	1	0.820	0.8400	0	0
I^{131}	8.6	12.9	7.5	91	3	0.081	0.0690	1.3	14.8
	17.1	26.0	7.3	115	5	0.094	0.0800	6.3	14.9
P^{32}	17.1	26.0	7.3	71	4	0.159	0.0130	90.2	91.7
	17.1	26.0	7.0	60	2	0.152	0.0088	81.1	94.2
	17.1	26.0	7.4	70	2	0.033	0.0022	93.2	93.3
	17.1	26.0	7.5	85	5	1.230	0.0530	87.5	93.9
	8.6	13.0	7.7	77	4	0.115	0.0154	86.5	86.5
	8.6	13.0	7.6	88	2	0.110	0.0088	90.0	92.0
	8.6	13.0	7.6	91	2	0.097	0.0066	93.2	93.2

* After coagulation, settling and centrifuging.

TABLE 2

Removal of Specific Radioisotopes by Alum and Na_2CO_3 Coagulation (3)

Radio-isotope	Dosage		Final Characteristics			Activity Total		Removals	
	Alum	Na_2CO_3	pH	Alkalinity	Turbidity	Initial	Final*	Coagulation and Settling	Coagulation, Settling and Centrifuging
	ppm.			*ppm.*		*million cpm.*		*per cent*	
Ce^{144}	17.1	203.7	7.8	83	3.0	1.050	0.092	64.8	91.2
	25.7	15.2	7.6	126	4.0	1.610	0.088	73.3	94.5
	25.7	15.2	7.2	124	4.0	0.300	0.057	82.7	81.0
Y^{91}	25.7	15.2	6.8	73	4.0	0.092	0.006	82.6	93.4
	25.7	15.2	7.1	27	0.4	0.030	0.005	93.3	83.3
Sr^{89}	25.7	15.2	7.8	32	3.0	1.700	1.600	5.8	5.8
	25.7	15.2	6.7	22	2.0	0.160	0.170	0	0
I^{131}	17.1	26.0	7.1	73	4.0	0.051	0.038	3.9	25.4
	17.1	25.9	8.7	44	2.0	0.940	0.980	0	0

* After coagulation, settling and centrifuging.

made on overall removal of radioactive contaminants by suspended and colloidal matter.

Coagulation

The results obtained in routine coagulation studies for the removal of radioactive Ce^{144}, Y^{91}, Sr^{89}, I^{131} and

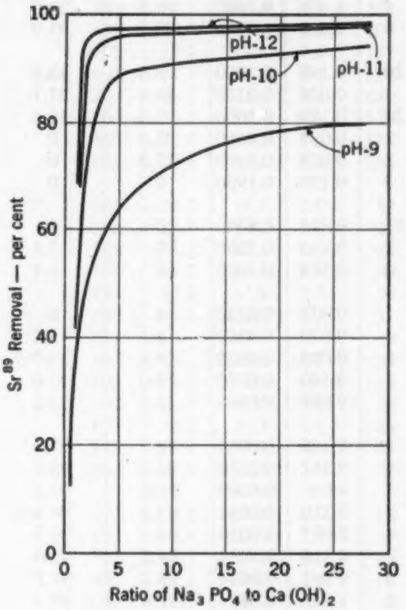

Fig. 3. Removal of Sr^{89}

The proportion of Sr^{89} removed from solution is shown as a function of the ratio of milligrams of Na_3PO_4 to milligrams of $Ca(OH)_2$ at 9–12 pH.

P^{32} will be reported under several headings: [1] alum and NaOH, [2] alum and Na_2CO_3, [3] alum and NaOH in the presence of turbidity, [4] alum and Na_2CO_3 in the presence of turbidity, [5] $FeCl_3$ and NaOH in the presence of turbidity and [6] $FeCl_3$ and Na_2CO_3 in the presence of turbidity. Iodine dissolver solution will be considered separately. As the conditions of test varied somewhat from run to run, all information obtained has been summarized in Tables 1–7. The procedure used in the coagulation studies consisted of the addition of radioisotope, coagulant and turbidity to tap water. This addition was followed by 3-minute rapid mixing, 27-minute slow mixing, 30-minute settling and centrifuging of the settled samples where indicated.

An examination of the data in these tables will show that:

1. The use of alum or iron with NaOH or Na_2CO_3 in the presence of turbidity always gave greater removals than did the use of the coagulating chemicals alone.

2. The use of Na_2CO_3 as compared with NaOH as a coagulant, with or without added turbidity, resulted in greater removal efficiencies and was particularly advantageous for Y^{91}, as removals with NaOH were less than 57 per cent and, with Na_2CO_3, were more than 83 per cent.

3. Chemical coagulation under the conditions reported was unsatisfactory for the removal of Sr^{89} and I^{131}.

4. Removals reported with $FeCl_3$ were slightly greater than those with alum, due probably to the broader pH range for effective coagulation with the iron salt. In the studies with iodine dissolver solution (Table 7), highest removals were obtained following coagulation with lime, alum and sodium silicate.

Auxiliary Procedures

Because little I^{131} could be removed by coagulation and settling, several additional techniques were investigated for the removal of this radioisotope.

TABLE 3

Removal of Specific Radioisotopes by Alum and NaOH Coagulation in Presence of Turbidity (3)

Radio-isotope	Dosage			Final Characteristics			Activity Total		Removals	
	Turbidity	Alum	NaOH	pH	Alkalinity	Turbidity	Initial	Final*	Coagulation and Settling	Coagulation, Settling and Centrifuging
	ppm.				*ppm.*		*million cpm.*		*per cent*	
Ce^{144}	103.0	8.6	13.7	7.3	89	4	1.560	0.1000	89.1	93.6
	103.0	25.7	45.6	7.0	64	4	1.600	0.1600	86.3	90.0
	103.0	42.8	88.1	7.1	59	4	1.540	0.0780	92.2	94.9
Y^{91}	103.0	8.6	13.7	6.8	73	20	0.190	0.1600	5.3	15.8
	103.0	25.7	18.2	6.8	26	3	0.028	0.0120	46.4	57.1
	103.0	25.7	45.6	6.8	73	20	0.190	0.1600	5.3	15.8
	103.0	34.2	25.8	6.9	25	2	0.028	0.0300	25.0	0
	103.0	42.8	38.9	6.8	23	2	0.028	0.0300	17.8	0
	103.0	42.8	88.1	6.8	69	3	0.190	0.1900	0	0
Sr^{89}	103.0	8.6	13.7	6.7	39	15	0.810	0.8300	0	0
	103.0	25.7	45.6	6.9	36	2	0.810	0.7500	0	7.4
	103.0	42.8	88.2	6.8	35	0	0.810	0.7600	0	6.1
I^{131}	34.3	8.6	12.9	7.4	89	1	0.078	0.0780	0	0
	68.6	8.6	12.9	7.5	91	4	0.079	0.0780	5.1	2.5
	103.0	8.6	12.9	7.5	113	4	0.095	0.0820	9.4	13.7
	103.0	17.1	26.0	7.3	107	5	0.100	0.0780	13.0	22.0
	103.0	25.7	38.9	7.3	113	4	0.098	0.0860	15.3	12.2
P^{32}	103.0	8.6	18.0	7.4	73	4	0.159	0.0044	94.5	97.3
	103.0	8.6	13.0	7.3	65	4	0.152	0.0022	94.3	98.6
	103.0	8.6	13.0	7.5	79	3	0.033	0.0009	96.6	97.3
	17.2	8.6	13.0	7.5	90	2	0.110	0.0044	92.1	96.0
	17.2	8.6	13.0	7.8	89	4	0.097	0.0044	95.5	95.3
	51.5	8.6	13.0	7.5	90	2	0.110	0.0044	94.0	96.0
	51.5	8.6	13.0	7.6	90	3	0.097	0.0044	93.2	97.7
	103.0	8.6	13.0	7.6	89	2	1.230	0.0374	91.6	97.1
	103.0	17.1	26.0	7.3	68	6	0.159	0.0066	93.1	95.8
	103.0	17.1	26.0	7.1	61	4	0.152	0.0022	88.4	98.6
	103.0	17.1	26.0	7.4	67	3	0.033	0.0013	97.2	96.0
	103.0	17.1	26.0	7.4	84	2	1.230	0.0176	94.7	98.7
	103.0	25.7	39.0	7.2	67	5	0.159	0.0044	94.5	97.3
	103.0	25.7	39.0	6.8	52	5	0.152	0.0022	97.2	98.6
	103.0	25.7	39.0	7.1	61	3	0.033	0.0011	93.2	96.6
	103.0	25.7	39.0	7.3	75	2	1.230	0.0153	96.2	98.8

* After coagulation, settling and centrifuging.

These procedures included the addition of variable amounts of activated carbon, copper sulfate or silver nitrate. The first two chemicals have found extensive application in the water works field in the control of tastes and odors. Silver salts have been suggested for use in disinfection.

The experimental results indicated in Table 8 show that these treatments proved beneficial. Of the three materials used, activated carbon may be

TABLE 4

Removal of Specific Radioisotopes by Alum and Na_2CO_3 Coagulation in Presence of Turbidity (3)

Radio-isotope	Dosage			Final Characteristics			Activity Total		Removals	
	Turbidity	Alum	Na_2CO_3	pH	Alkalinity	Turbidity	Initial	Final*	Coagulation and Settling	Coagulation, Settling and Centrifuging
	ppm.				*ppm.*		*million cpm.*		*per cent*	
Ce^{144}	103	8.6	158.4	7.6	75	1.0	1.040	0.037	94.7	96.4
	103	17.1	256.4	7.8	101	3.0	1.070	0.017	91.0	98.4
	103	25.7	281.2	7.8	107	2.0	1.090	0.037	92.4	96.6
	103	25.7	18.4	7.6	127	6.0	1.640	0.100	80.5	93.9
	103	25.7	18.2	7.4	126	4.0	0.310	0.040	87.7	87.1
	103	34.2	27.1	7.4	129	3.0	1.630	0.059	84.7	96.4
	103	34.2	25.8	7.5	136	3.0	0.300	0.030	93.7	90.0
	103	42.8	33.7	7.6	127	0.8	1.550	0.069	92.3	95.5
	103	42.8	33.4	7.4	154	3.0	0.320	0.032	95.3	90.0
Y^{91}	103	25.7	18.2	7.0	52	4.0	0.094	0.003	93.7	96.8
	103	25.7	18.2	7.3	31	0.0	0.036	0.003	94.4	91.6
	103	34.2	27.1	7.2	43	3.0	0.094	0.003	95.8	96.8
	103	34.2	25.8	7.1	34	0.0	0.030	0.003	93.3	90.0
	103	42.8	33.8	7.2	39	3.0	0.098	0.003	96.0	97.0
	103	42.8	38.9	7.2	31	0.0	0.029	0.003	93.1	89.6
Sr^{89}	103	25.7	18.2	7.7	35	2.0	1.700	1.500	5.8	11.7
	103	25.7	18.2	7.0	21	2.0	0.160	0.130	5.2	18.7
	103	34.2	27.0	7.8	36	2.0	1.700	1.500	11.7	11.7
	103	34.2	25.8	7.2	26	1.0	0.170	0.150	11.7	11.7
	103	42.8	33.7	7.9	41	3.0	1.700	1.500	17.6	11.7
	103	42.8	33.4	7.1	26	1.0	0.160	0.150	6.2	6.2
I^{131}	103	8.5	12.5	8.7	54	2.0	0.950	0.850	3.1	10.5
	103	8.6	12.9	7.3	83	1.0	0.049	0.038	0	22.4
	103	17.1	25.9	8.8	49	2.0	0.910	0.940	0	0
	103	17.1	26.0	6.9	73	4.0	0.048	0.052	0	0
	103	25.7	38.9	8.9	53	3.0	0.950	0.970	0	0
	103	25.7	38.9	6.9	56	10.0	0.051	0.043	1.9	15.6

* After coagulation, settling and centrifuging.

preferable as it effects comparatively high removals and may be used in combination with routine coagulation techniques effective for the removal of certain radioisotopes.

Phosphate Coagulation

As the number of highly insoluble phosphates exceeds the number of insoluble hydroxides (5), employing a modified coagulation technique, tracer-type runs were carried out with isotopes of Ce^{144}, Sr^{89}, Sb^{124}, Zn^{65}, W^{185}, Zr^{95} and Nb^{95} added individually to distilled water. The floc was formed by mixing $Ca(OH)_2$ and either KH_2PO_4 or Na_3PO_4 at a pH value of approximately 11.5. This floc was then separated by both settling and centrifuging processes. Some typical results for one-stage batch treatment are presented in Table 9.

TABLE 5

Removal of Specific Radioisotopes by $FeCl_3$ and NaOH Coagulation in Presence of Turbidity (3)

Radioisotope	Dosage			Final Characteristics			Activity Total		Removals	
	Turbidity	$FeCl_3$	NaOH	pH	Alkalinity	Turbidity	Initial	Final*	Coagulation and Settling	Coagulation, Settling and Centrifuging
	ppm.				*ppm.*		*million cpm.*		*per cent*	
Ce^{144}	103	8.6	15.2	7.7	101	4	1.400	0.069	96.0	95.1
	103	25.7	33.4	7.6	94	11	1.390	0.047	56.1	96.6
	103	42.8	50.2	7.3	80	7	1.440	0.040	95.9	97.2
Y^{91}	103	8.5	38.0	8.0	36	8	0.160	0.088	37.5	45.0
	103	8.6	15.2	6.9	35	10	0.180	0.130	22.2	27.2
	103	25.7	33.4	6.8	36	9	0.180	0.140	16.6	22.2
	103	25.7	53.2	8.0	34	7	0.150	0.088	26.6	45.0
	103	42.8	49.2	6.8	38	8	0.180	0.120	16.6	33.3
	103	42.8	76.0	8.1	35	7	0.150	0.100	20.0	33.3
Sr^{89}	103	8.6	15.2	7.1	34	5	0.790	0.620	20.2	21.5
	103	25.7	33.4	6.9	33	4	0.790	0.700	11.3	11.3
	103	42.8	50.1	6.8	39	20	0.790	0.710	10.1	10.1
I^{131}	103	8.5	12.5	9.0	98	2	0.096	0.100	0	0
	103	8.5	12.5	9.0	96	2	0.530	0.570	0	0
	103	8.6	12.9	8.5	103	4	0.100	0.090	0	10
	103	17.1	25.9	9.0	96	2	0.760	0.880	0	0
	103	17.1	25.9	9.1	97	1	0.640	0.530	6.2	17.2
	103	17.1	26.0	8.7	101	3	0.097	0.094	0	3.1
	103	25.7	38.9	8.9	104	10	0.096	0.100	0	0
	103	25.7	38.9	8.9	95	1	0.710	0.740	0	0
	103	25.7	38.9	9.0	96	1	0.630	0.610	0	3.1

* After coagulation, settling and centrifuging.

Because of the variation found in the removal of Sr^{89}, this radioisotope was selected for further study. The effect of the $Na_3PO_4:Ca(OH)_2$ ratio and pH is shown in Fig. 3. Removals in excess of 90 per cent could be obtained at a pH of more than 11 and a $Na_3PO_4:Ca(OH)_2$ ratio of more than 2. In these tests, 55 ppm. of $Ca(OH)_2$ were always used in conjunction with sufficient Na_3PO_4 to give the indicated ratios. When necessary, the pH was adjusted by the addition of dilute NaOH.

Further runs using phosphate precipitation were made to treat wastes containing mixed fission products, and removals of 98.8 to 99.7 per cent were reported when 100 ppm. clay and 100 ppm. Na_3PO_4 were added to the initial solutions.

Ion Exchange

With the newer, high-capacity synthetic cation and anion resins, many radioactive elements may be removed from large volumes of dilute wastes. The use of the newer resins, particularly in monobed units, was studied. Lauderdale and Emmons (6) used this principle as the final step in a decontamination unit that included passage

TABLE 6

Removal of Y^{91} by $FeCl_3$ and Na_2CO_3 Coagulation in Presence of Turbidity (3)

Radio-isotope	Dosage			Final Characteristics			Activity Total		Removals	
	Turbidity	$FeCl_3$	Na_2CO_3	pH	Alkalinity	Turbidity	Initial	Final*	Coagulation and Settling	Coagulation, Settling and Centrifuging
	ppm.				*ppm.*		*million cpm.*		*per cent*	
Y^{91}	103	8.6	30.4	8.2	26	0.5	0.17	0.009	90.5	94.7
	103	25.7	45.6	8.3	30	2.0	0.16	0.005	95.0	96.8
	103	42.8	45.6	8.5	27	2.0	0.16	0.003	94.0	98.1

* After coagulation, settling and centrifuging.

of the radioactively contaminated solution through layers of steel wool, burnt clay and activated carbon. This combination of processes, which incidentally has been suggested for the emergency treatment of small volumes of water (approximately 30 l.) contaminated with radioactivity, resulted in the reduction of the initial concentration from 2.5 microcuries (μc) per ml. to less than 10^{-4} μc per ml., which is equivalent to a removal of more than 99.996 per cent.

Pilot Plant Tests

To test laboratory findings on a larger scale, a small experimental water treatment plant of approximately 250 gpd. (1,000 l. per day) capacity was designed and built. This experimental plant included the conventional facilities for mixing, flocculation, sedimentation and filtration, and the results obtained will be helpful in establishing basic criteria for the design of larger pilot or full scale plant units and for

TABLE 7

Removal of Radioactivity From Iodine Dissolver Solution (3)

Turbidity			Lime			Lime and Alum				Lime, Alum and Sodium Silicate				
Dosage	Initial pH	Removal	Dosage	Initial pH	Removal	Dosage: Lime	Dosage: Alum	Initial pH	Removal	Dosage: Lime	Dosage: Alum	Dosage: Na_2SiO_3	Initial pH	Removal
ppm.		*per cent*	*ppm.*		*per cent*	*ppm.*			*per cent*	*ppm.*				*per cent*
50	7.6	28.4	9	8.8	39.3	51	9	8.8	67.0	0	51	6	7.5	59.2
100	7.6	34.9	17	—	43.4	51	17	8.8	70.2	6	51	6	7.6	61.0
200	7.6	50.2	9	9.0	61.2	51	26	8.7	73.5	12	51	6	8.2	64.2
400	7.6	52.2	34	—	65.4	51	34	8.6	76.1	24	51	6	8.5	72.4
800	7.6	64.1	51	9.0	80.0	51	51	8.4	74.4	51	51	6	8.6	84.2
						0	51	7.2	56.0					
						6	51	7.4	50.2					
						12	51	7.5	60.5					
						24	51	7.8	62.9					
						51	51	8.4	70.7					

suggesting modifications in operating procedures.

The mixing, flocculation and settling basins are of stainless steel and are shown in Fig. 4. The ten rapid sand and Anthrafilt * filter columns are shown in Fig. 5. A complete description of the plant has been given elsewhere (2).

The experimental plant has been used to evaluate the effectiveness of conventional water treatment processes (alum coagulation, sedimentation and filtration) in removing radioactive phosphorus (P^{32}), radioactive iodine (I^{131}) and a synthetic mixture of fission products which would be typical of residual activity one month after the blast of a nuclear bomb.

It may seem that there is little necessity to study P^{32} and I^{131}, which are both short-lived materials (14.3- and 8-day half-life, respectively) and therefore should not result in serious haz-

TABLE 8

Removal of I^{131} by Auxiliary Processes (3)

Dosage				Final Characteristics			Activity Total		Removals	
Turbidity	Alum	NaOH	Auxiliary Chemical	pH	Alkalinity	Turbidity	Initial	Final*	Coagulation and Settling	Coagulation, Settling and Centrifuging
ppm.					*ppm.*		*million cpm.*		*per cent*	
103.0	25.7	38.9	5.00†	7.1	67	0	0.110	0.028	68.2	74.5
103.0	25.7	38.9	10.00†	7.1	68	1	0.100	0.026	64.0	74.0
103.0	25.7	38.9	15.00†	7.1	68	0	0.110	0.027	70.9	75.4
103.0	25.7	38.9	15.00†	5.8	17	15	0.400	0.089	72.5	77.7
103.0	25.7	38.9	3.50‡	7.1	65	0	0.120	0.053	38.3	55.8
17.3	25.7	38.9	3.80§	7.5	54	15	0.071	0.024	61.9	66.1
34.3	25.7	38.9	3.80§	7.4	63	20	0.068	0.028	61.7	58.8
34.3	25.7	38.9	3.80§	7.3	70	8	0.092	0.026	43.4	71.7
68.6	25.7	38.9	3.80§	7.4	66	6	0.062	0.026	50.0	58.0
68.6	25.7	38.9	3.80§	7.5	64	20	0.071	0.027	63.3	61.9
103.0	25.7	38.9	3.80§	6.9	63	1	0.110	0.026	73.6	76.3
103.0	25.7	38.9	3.80§	7.5	72	20	0.072	0.026	62.5	63.8
103.0	25.7	38.9	0.12§	7.1	73	20	0.075	0.033	44.0	56.0
103.0	25.7	38.9	0.30§	7.3	68	15	0.067	0.031	52.2	53.7
103.0	25.7	38.9	0.63§	7.3	73	25	0.068	0.031	54.4	54.4
103.0	25.7	38.9	1.30§	7.1	66	30	0.071	0.037	54.9	47.8
103.0	25.7	38.9	2.50§	7.2	65	40	0.068	0.034	42.6	50.0
103.0	25.7	38.9	3.80§	5.8	19	5	0.410	0.096	73.1	76.5
137.0	25.7	38.9	3.80§	7.4	53	8	0.082	0.024	47.5	70.7
137.0	25.7	38.9	3.80§	7.5	74	15	0.064	0.023	59.3	64.0
	25.7	38.9	3.80§	7.3	56	10	0.083	0.027	57.8	67.4
274.0	25.7	38.9	3.80§	7.3	58	10	0.078	0.026	46.1	66.6

* After coagulation, settling and centrifuging.
† Auxiliary chemical was activated carbon.
‡ Auxiliary chemical was copper sulfate ($CuSO_4 \cdot 5H_2O$).
§ Auxiliary chemical was silver nitrate ($AgNO_3$).

* A product of Anthracite Equipment Corp., Wilkes-Barre, Pa.

ards. Although these substances are not hazardous at present, they are used extensively in research and medicine. Data available have shown that during the period from August 1946 through December 1950, approximately 1,229 curies, which includes 507 curies of I^{131} and 189 curies of P^{32} (7), were shipped to off-Commission (non-AEC) users. If the 445 curies of Co^{60} (metal) shipped are deducted from the overall total, it will be seen that the I^{131} and P^{32} constitute about 65 and 24 per cent, respectively, of the radioisotopes shipped. At present, the probability of finding I^{131} and P^{32} in sewage discharges and water courses is, therefore, considerably greater than that of finding any other radioisotopes, although the concentrations found will probably be insignificant.

Removal of P^{32}

Table 3 shows that laboratory studies using alum coagulation in the presence of turbidity effected 95–98 per cent removals of P^{32}. Pilot plant studies (8) were made to check these results and to evaluate removals on a continuous flow basis under conditions simulating conventional practice. In these studies, the coagulating chemicals (alum and NaOH), P^{32} and the raw water were fed to the plant by gravity. Turbidity in the form of a clay slurry was fed through the Harvard-type roller displacement pump. Hourly measurements were made of the amounts of

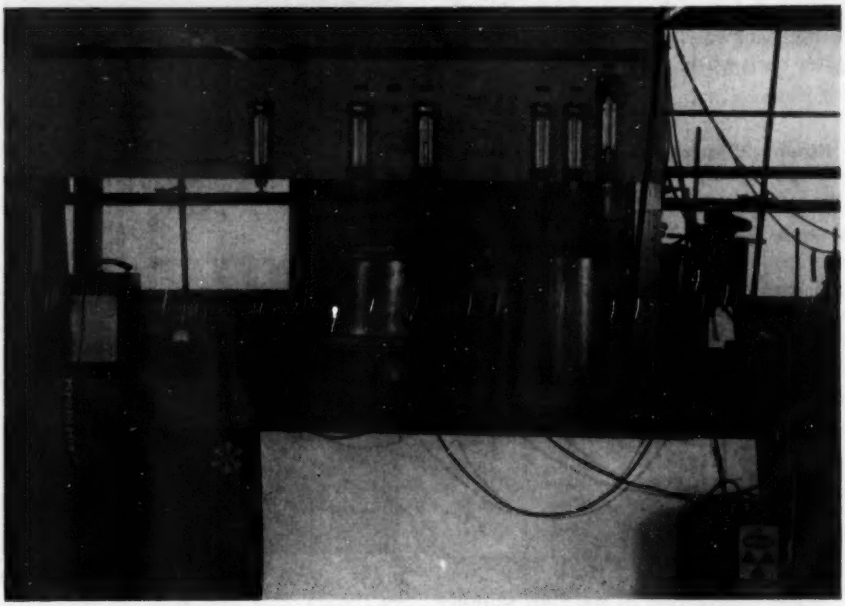

Fig. 4. Water Treatment Pilot Plant

The mixing and flocculation equipment and settling basin appear in this study of the pilot plant.

alum, alkali, P^{32}, turbidity, raw and filtered water through the plant. The computed daily average dose rates are given in Table 10.

Samples for measurement of radioactivity were collected every half hour at the influent end of the flocculation basin (mixed sample) and at the effluent end of the settling basin (settled sample). Filter effluent samples were collected from alternate filters hourly. Filter backwash water was also sampled after each wash.

TABLE 9

Results of Phosphate Coagulation Studies (5)

Isotope	Coagulant		Removal *per cent*
	Symbol	Amount—*ppm.*	
Ce^{144}	KH_2PO_4	200	99.8
	Na_3PO_4	120	99.9
Sr^{89}	KH_2PO_4	100	81.3
	Na_3PO_4	240	97.8
Y^{91}	KH_2PO_4	100	99.9
Sb^{124}	KH_2PO_4	100	66.1
	Na_3PO_4	120	67.4
Zn^{65}	KH_2PO_4	50	99.6
W^{185}	KH_2PO_4	200	10.7
Zr^{95}	KH_2PO_4	100	99.5
Nb^{95}	KH_2PO_4	100	99.2

After completion of the run, samples were taken to determine the residual radioactivity in the mixing, flocculation and settling basins (both supernatant and sludge). The filters were backwashed, samples were collected and the residual activities in the sand and gravel layers comprising the filter column were determined. With the exception of the sludge samples, 10-ml. volumes were placed in aluminum counting dishes, dried under infrared heat lamps and counted in a Geiger-Mueller end-window counter. All counts were corrected to the same initial time to compensate for radioisotope decay. Analyses for pH, turbidity and alkalinity were made at intervals of 4 hours and are reported in Table 11. Data on filter operation will be found in Table 12.

The variation in the measured activity in the plant units is indicated by the values given in Table 13 and shown

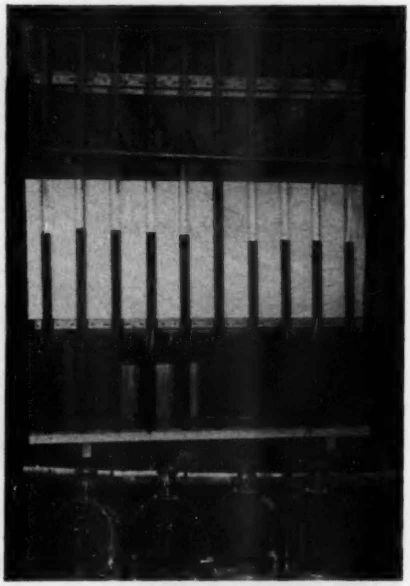

Fig. 5. Pilot Plant Filtration Equipment

The rapid sand and Anthrafilt filters are featured in this study of the pilot plant. Filter No. 6 (from left) is being backwashed as evidenced by the expanded sand bed.

in Fig 6. The measured activity values were averaged for the total period noted in Table 13 and are: mixing basin effluent, 1708; settling basin effluent, 206; left filter effluent, 35; right filter effluent, 40 disintegrations per minute per ml. (dpm. per ml.). Removal efficiencies computed on the basis of these data were 87.9 per cent for co-

TABLE 10

Chemical Dosages for P^{32} Removal

Date	Raw Water Flow—*gpd.*	Turbidity *ppm.*	Dosage—*ppm.*		P^{32} Addition *ml. per minute*
			Alum	NaOH	
8/ 9/49	248	110	15	13	6.5
8/10/49	254	95	9	9	14.0
8/11/49	246	100	10	10	20.5
8/12/49	248	100	9	9	19.6

agulation and settling, 77.7–83.0 per cent for filtration alone, and 97.3–97.9 per cent for settling and filtration. Proportional removals were also computed on the basis of a radioactive materials balance; that is, accounting for residual activity in the sludge, backwash water and other such items. These removals were as follows: coagulation and sedimentation 84.9 per cent and filtration 76.5–84.4 per cent for an overall removal of 96.4–97.6 per cent. These values can be seen to compare favorably with those reported above.

Measurements of activity in the sand filters indicate that there was a marked decrease in activity with depth. This information is shown in Table 14. A portion of the sand from one of the filters was taken, and various solvents were employed to remove the P^{32} attached to the sand grains. In all leaching experiments, the results of which are given in Table 15, 1 g. of sand was leached with 50 ml. of solvent. With nitric, sulfuric and hydrochloric acids, these solutions consisted of 45 ml. of water and 5 ml. of the concentrated reagent. For NaOH, 45 ml. of water and 5 ml. of 6*M* NaOH were used. The results indicated that HCl and NaOH were most effective in removing P^{32} from the sand. It is evident, therefore, that P^{32} is not effectively removed by water, and it may be advisable to provide other solvents for backwashing the filters.

The effluent from the filters averaged 37 dpm. per ml. which corresponds to 1.7×10^{-5} μc per ml. As the maximum permissible concentration for continuous exposure to P^{32} over a prolonged period is reported to be 2×10^{-4} μc per

TABLE 11

Results of Chemical Analyses in P^{32} Removal

Date	Raw*			Mixed			Settled			Left Filter			Right Filter		
	pH	Alkalinity	Turbidity	pH	Alkalinity	Turbidity	pH	Alkalinity	Turbidity	pH	Alkalinity	Turbidity	pH	Alkalinity	Turbidity
		ppm.			*ppm.*			*ppm.*			*ppm.*			*ppm.*	
8/ 9/49	7.2	82.1	0.3	7.4	88.6	120	7.4	82.3	8	7.5	81.9	0.1	7.5	80.3	<0.1
8/10/49	7.3	81.7	<0.1	6.7	55.7	110	7.1	57.7	7	7.3	64.7	<0.1	7.4	63.3	<0.1
8/11/49	7.3	84.3	<0.1	7.1	68.5	110	7.2	63.5	10	7.4	68.2	<0.1	7.4	66.6	<0.1
8/12/49	7.3	83.3	<0.1	7.5	74.3	95	7.3	77.0	7	7.4	72.0	<0.1	7.4	73.3	<0.1

* Raw water is tap water.

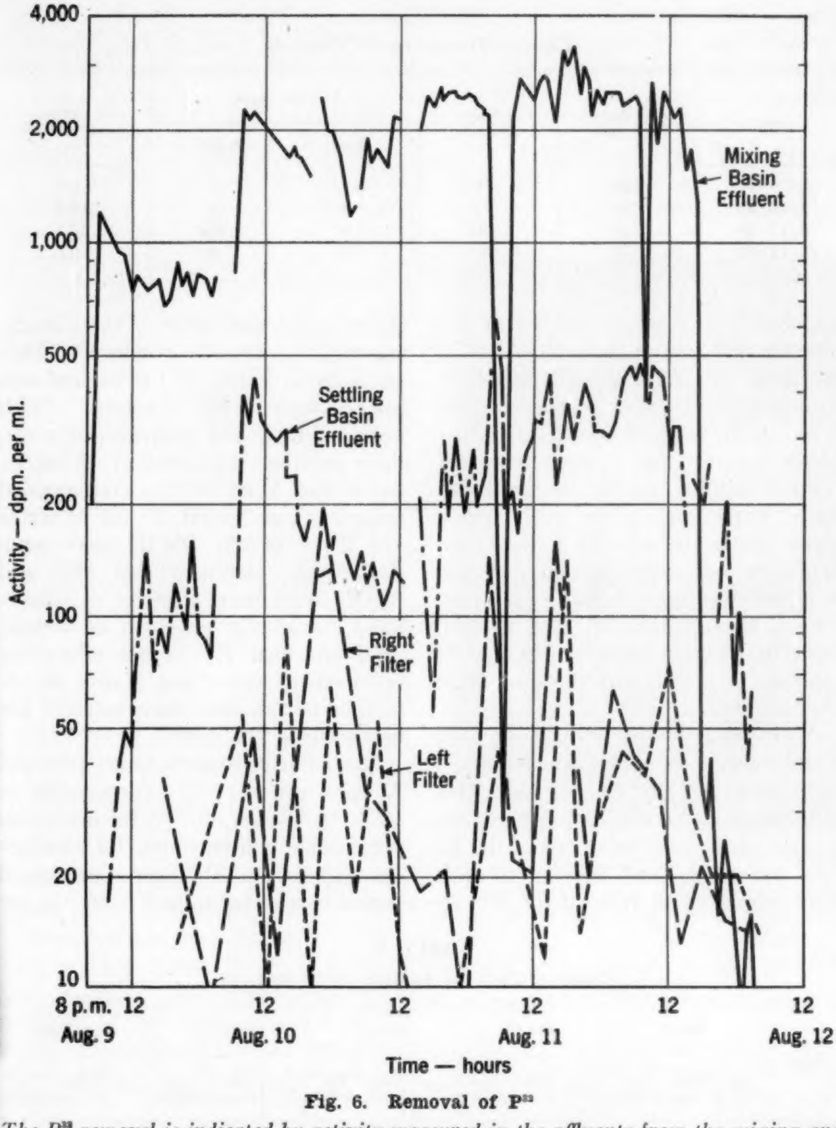

Fig. 6. Removal of P^{32}

The P^{32} removal is indicated by activity measured in the effluents from the mixing and settling basins and two rapid sand filters.

ml. (3), it will be seen that the effluent contained about one-tenth of this concentration and would be satisfactory for use without further treatment. Of course the initial concentration would have to be equal to or lower than that used in the experiment described. Greater initial concentrations would

TABLE 12

Filter Operation Data for P^{32} Removal

Date	Operating Time	Left Filter					Right Filter				
		Flow	Times Washed	Avg. Operating Time Between Washes	Operating Time	Wash Water Used	Flow	Times Washed	Avg. Operating Time Between Washes	Operating Time	Wash Water Used
	hours	*mgd./acre*		*hours*	*per cent*		*mgd./acre*		*hours*	*per cent*	
8/ 9/49	9.50	100.0	—	—	—	—	107.1	—	—	—	—
8/10/49	24.00	131.6	1	29.45	99.5	2.2	107.5	1	26.93	98.4	3.0
8/11/49	24.00	135.7	1	18.95	98.2	4.0	111.0	—	—	—	—
8/12/49	9.75	130.7	1	17.58	—	—	112.9	1	38.90	—	—

result in greater effluent counts if it is assumed that comparable removals would occur. The permissible effluent concentration, which is set by the maximum permissible concentration for the given radioisotope and the effectiveness of the treatment process define the maximum initial concentration.

Removal of I^{131}

Pilot plant runs involving the removal of I^{131} by alum coagulation and by alum coagulation plus 4 ppm. activated carbon resulted in the activity reductions shown in Fig. 7 and 8. The chemical dosages applied during these runs are shown in Table 16. Chemical treatment, as defined by the coagulant dosages given in Table 16 under Series A, was ineffective in the removal of I^{131}. It was possible to demonstrate a removal of 0.4 per cent following sedimentation, but only through the recovery of I^{131} from the settled sludge. Filtration did not result in any measurable removal of the I^{131}. Reference to Fig. 7 will indicate that after 6 A.M. on July 29, equilibrium seems to have been established as all samples—mixed, flocculated, settled and filtered—show approximately the same effluent activity of approximately 370 cpm. per ml.

TABLE 13

P^{32} Radioactivity in Plant Effluents

Date	Time Interval	Activity—*dpm. per ml.**			
		Mixing Basin	Settling Basin	Left Filter	Right Filter
8/ 9–10/49	8:00 P.M.–4:00 A.M.	823	61	44	36
8/10/49	4:00 A.M.–12:00 NOON	1,279	211	27	25
8/10/49	12:00 NOON–8:00 P.M.	1,724	188	46†	84†
8/10–11/49	8:00 P.M.–4:00 A.M.	2,021	139	21	25
8/11/49	4:00 A.M.–12:00 NOON	1,965	280	21	46
8/11/49	12:00 NOON–8:00 P.M.	2,607	342	47†	79
8/11–12/49	8:00 P.M.–4:00 A.M.	1,535	424	40	27
8/12/49	4:00 A.M.–9:45 A.M.	18	91	16†	14†

* The term disintegrations is used rather than counts because corrections have been made to the raw data for coincidence, background, geometry and decay.

† Filter washed during or just after this period.

TABLE 14

P^{32} Activity in the Filter Sand

Depth from Top *in.*	Activity in Sand—*dpm. per g.*	
	Left Filter	Right Filter
0–6	62,201	36,791
6–12	9,637	6,445
12–18	5,184	2,489
18–24	4,770	5,709
24–30	479	2,811
Gravel	748	1,058

(at 10 per cent geometry *). When activated carbon was added, a reduction of 15.5 per cent of the I^{131} was obtained by coagulation and settling and 11.3 per cent by filtration alone, for an overall reduction of 25.0 per cent. Although the addition of 4 ppm. of activated carbon was somewhat helpful in increasing the removal of I^{131}, the results obtained were far below the values indicated by the laboratory studies (Table 8). One possible explanation of the differences in reported results may be the method used for addition of activated carbon. The activated carbon was mixed with the clay slurry but, being very light, did not mix well even though aeration was provided for that purpose. The activated carbon separated out, forming rings on the sides of the containers at the water surface. Use of a coarser grade of carbon might have lessened this difficulty.

* Ten per cent of total disintegrations were collected and registered by counter.

TABLE 15

*Sand Leaching Experiments—P^{32}**

Treatment†	Activity of Sand—*dpm. per g.*		
	In Leaching Solution	In Sand	Total
Untreated	—	21,600	21,600
Water	2,376	17,366	19,742
Nitric acid	9,331	2,592	11,923
Sulfuric acid	9,979	1,145	11,124
Hydrochloric acid	16,416	2,722	19,138
Sodium hydroxide	16,524	6,113	22,637

* Sand taken from top 6 in. of left filter.
† See text for concentrations used.

Mixed Fission Products

A synthetic solution (10) was prepared to simulate the elements and products remaining approximately one month after a nuclear bomb blast. Only the major elements resulting from the blast were included, and the composition was based somewhat on the radioisotopes available at the time of the study. It is further recognized that no attempt was made to simulate chemical composition of the respective chemical compounds produced during a nuclear explosion. Since gross removals, although of interest, would have little significance, radiochemical analyses were made of composite settled and filtered effluent samples.

TABLE 16

Chemical Dosages for I^{131} Removal

Chemical	Dosage—*ppm.*	
	Series A*	Series B†
Aluminum sulfate	26	26
Lime	26	26
Activated carbon	—	4
Turbidity	93	102
Sodium silicate	6	7

* Alum treatment.
† Alum treatment plus 4.0 ppm. activated carbon.

The radioelements comprising the mixture are noted with other pertinent data in Table 17. Chemical dosages are shown in Table 18. The initial count, 675 cpm. per ml. (at 10 per cent geometry), was proportioned according

to the percentage of each radioisotope included in the mixture, and the values obtained were assumed to be representative of the initial concentration of each radioisotope in the mixture treated in the plant. These initial values and

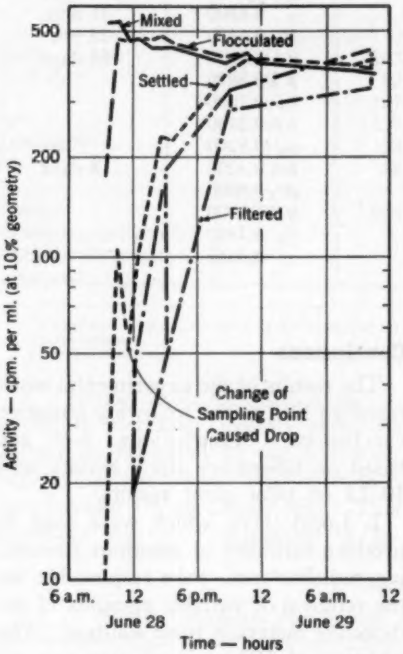

Fig. 7. Removal of I^{131}

This removal is measured by the activity found in the effluents from the mixing, flocculation and settling basins, and the ten filter columns. The filter data are shown as an envelope of values since actual plotting of these curves is impracticable.

the values obtained by radiochemical analyses of the various effluent samples are given in Tables 19 and 20.

A gross removal of 46.5 per cent of the radioactivity may be attributed to coagulation and settling. Filtration accounted for an additional 44–50 per cent removal. Overall removals were 73 and 70 per cent for coagulation, settling and filtration through sand or Anthrafilt, respectively. A study of the data in Table 20 will show differences in the amounts of the specific radioactive substance removed and some apparent variations in removal after passage through the sand or Anthrafilt

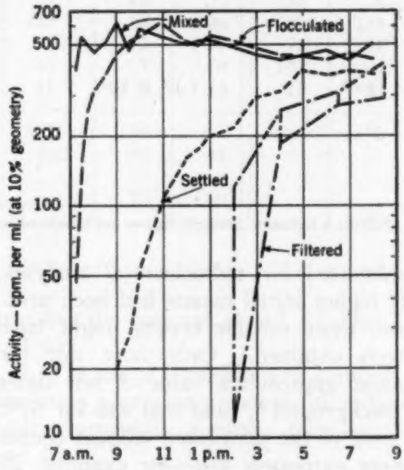

Fig. 8. Removal of I^{131} by Auxiliary Process

The effect of addition of 4 ppm. activated carbon on I^{131} removal is indicated by the activity measured at various points in the treatment plant. Filter data are shown as an envelope of values for ease in plotting. Period of study covers from 7 A.M. to 9 P.M., August 5, 1950.

columns. These differences require further investigation. If the specific removals are compared with the results of the laboratory studies, in which some of the same radioisotopes were investigated discrepancies will be found. These discrepancies are partly due to the exceedingly small quantities of radioisotopes involved in the samples

TABLE 17

Bomb Blast Mixture—Age One Month

Radioisotope	Activity of Original Mixture—*cpm. per ml.*	Proportion of Radioisotopes in Initial Mixture—*per cent*	Energy—*Mev.*	Half-Life
Ru^{106}	5.5×10^8	15.9	β^- 0.0410	1 yr.
Ce^{144}–Pr^{144}	4.19×10^8	12.1	β^- 0.3480	275 days
Y^{91}	6.2×10^8	17.9	γ 0.6100	51 min.
Sr^{90}	12.24×10^8	35.4	β^- 0.5370	25 yrs.
Zr^{95}–Nb^{95}	5×10^8	14.5	β^-_1 0.4000	65 days
			β^-_2 0.8870	
			γ_1 0.7080	
			γ_2 0.2160	
			γ_3 0.9200	
I^{131}*	1.47×10^8	4.2	β^-_1 0.3200	8 days
			β^-_2 0.6000	
			γ_1 0.0800	
			γ_2 0.2840	
			γ_3 0.3642	

* Other γ radiation released: figures not tabulated here.

submitted for radiochemical analyses. If higher initial counts had been present, more reliable results might have been obtained. Only once did the count approach a value of ten times "background *," and that was for Sr^{90}. Some of the pilot plant effluent counts were extremely low—for example, 28 cpm. per ml. (at 10 per cent geometry) for the I^{131}, which is slightly higher than background.

TABLE 18

Chemical Dosage Rates for Fission Products Mixture

Chemical	Dosage *ppm.*
Turbidity	104
Aluminum sulfate	15
Lime	14
Sodium silicate	7
Radioisotope solution*	—

* Dosage is 11.5 ml. per liter of flow (average).

* Counts from cosmic rays, nearby radioactive materials and other sources normally present but with no sample exposed in counter.

Conclusions

The results of the experimental work reported lead to the following tentative conclusions. Conclusions 1–9 are based on laboratory study results, and 10–13 on pilot plant results.

1. Local clays, which were used to produce turbidity in solutions containing radioisotopes, were responsible for the removal of variable amounts of radioactive materials from solution. The addition of 100 ppm. of clay was effective in removing as much as 80 per cent of the Ce^{144}, 46 per cent of the Y^{91}, 34 per cent of the P^{32}, 30 per cent of the Sr^{89} and 29 per cent of the iodine dissolver solution from liquids containing the specific radioelements.

2. Coagulation with alum and NaOH resulted in varied removals of individual radioisotopes. For example, as much as 89 per cent of the Ce^{144}, 35 per cent of the Y^{91}, 15 per cent of the I^{131} and 94 per cent of the P^{32} could be removed. No removal of the Sr^{89} was indicated.

TABLE 19

Radioactivity Measurements of Fission Products Mixture

Radioisotope	Proportion of Radioisotope Added to Initial Mixture—*per cent*	Activity in Initial Mixture—*cpm./ml.**	Final Activity—*cpm./ml.*				
			Settled Water Second Basin	Effluent Filters		Backwash Water Filters	
				1–8†	9–10‡	1–8†	9–10‡
Ru^{106}	15.9	107	27	27	19	73	64
Ce^{144}–Pr^{144}	12.1	82	37	18	20	153	78
Y^{91}	17.9	121	146	88	86	209	128
Sr^{90}	35.4	239	93	72	77	73	51
Zn^{95}–Nb^{95}	14.5	98	31	7	10	192	90
I^{131}	4.2	28	17	8	16	14	12
TOTALS	100.0	675	361	180	203	689	390
REMOVAL—*per cent*			46.5	50	44		
OVERALL REMOVAL—*per cent*				73	70		

* Calculated from initial value of 675 cpm. per ml.
† Sand columns.
‡ Anthrafilt columns.

3. The use of Na_2CO_3 and alum coagulation increased overall removals slightly as indicated by the following values: Ce^{144} to 94 per cent, Sr^{89} to 6 per cent and I^{131} to 25 per cent. This treatment was very successful in increasing the removal of Y^{91} (Tables 2 and 4).

4. The use of turbidity with alum coagulation increased removals of radioactive materials slightly (Tables 3 and 4).

TABLE 20

Removal of Specific Radioisotope Activity by Water Treatment Processes

Radioisotope	Activity—*cpm./ml.*							Removals—*per cent*				
								Filtration			Overall	
	Initial*	Settled	Difference	Filtered 1–8†	Difference	Filtered 9–10‡	Difference	Settling	1–8†	9–10‡	Settling +1–8†	Settling +9–10‡
Ru^{106}	107	27	−80	27	0	19	−8	75	0	30	75	82
Ce^{144}–Pr^{144}	82	37	−45	18	−19	20	−17	55	51	46	78	76
Y^{91}	121	146	+25	88	−58	86	−60	—	40	41	48	50
Sr^{90}	239	93	−146	72	−21	77	−16	61	23	17	70	68
Zr^{95}–Nb^{95}	98	31	−67	7	−24	10	−21	68	78	68	93	90
I^{131}	28	17	−11	8	−9	16	−1	39	53	6	72	43
TOTAL	675							46	50	44	73	70

* Calculated.
† Sand columns.
‡ Anthrafilt columns.

5. The action of $FeCl_3$ as a coagulant was similar to that of alum, although the removals were slightly greater (Tables 5 and 6).

6. A 60–80 per cent reduction in activity of mixed fission products in iodine dissolver solution can be effected by chemical coagulation (Table 7).

7. The removal of I^{131} by alum coagulation could be substantially enhanced by the addition of small amounts of activated carbon, copper sulfate or silver nitrate. Removals of as much as 78 per cent were obtained.

8. Phosphate coagulation was particularly effective in the removal of Ce^{144}, Y^{91}, Zn^{65}, Zr^{95}, Nb^{95} and mixed fission products.

9. Under suitable conditions with control of pH and the $Na_3PO_4:Ca(OH)_2$ ratio, more than 90 per cent of the Sr^{89} could be removed.

10. Coagulation, settling and filtration on a pilot plant scale was effective in removing 96–98 per cent of the P^{32} contained in a water solution.

11. No measurable removal of I^{131} was obtained by coagulation, settling and filtration under the conditions reported herein.

12. The supplemental addition of 4 ppm. of activated carbon to the coagulation procedure resulted in the overall removal of approximately 26 per cent of the I^{131}, but removals were about one-third of those indicated by laboratory studies.

13. Approximately 70 per cent of the radioactive materials contained in the fission products mixture used could be removed by coagulation, sedimentation and filtration.

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Improved Coagulation by the Use of Pulverized Limestone

By Charles H. Spaulding, Harry N. Lowe Jr. and Richard P. Schmitt

A contribution to the Journal by Charles H. Spaulding, Urbana, Ill., Harry N. Lowe Jr., Deputy Chief, and Richard P. Schmitt, Chief, both of Water Purif. Sec., Engr. Research and Development Labs., Water Supply Branch, Fort Belvoir, Va.

IMPROVED coagulation for military water purification became desirable during World War II as a result of the use of diatomite filters. These, in turn, had been adopted because sand filters, as operated in the field, offered inadequate protection against amebic cysts (1, 2). Later research studies and reexamination of the literature have suggested better materials and methods of coagulation for use either with new or existing equipment. Other studies made to improve the equipment itself will not be discussed in this article.

Importance of Coagulation

Good coagulation is the secret of good filtration whether the filter medium is coarse sand or diatomaceous silica. When coarse sand filters were introduced at the end of the nineteenth century, they were sometimes called "alum" filters to distinguish them from the fine sand predecessors. Coagulation is an integral part of rapid sand filtration, for without it neither bacteria nor colloidal solids can be removed by coarse sand.

It is possible, of course, for diatomaceous silica to remove amebic cysts (1, 2) and a large proportion of bacteria or colloids without coagulation. On occasion, satisfactory clarity and purification can be produced without pretreatment of the raw water. The usual surface water, however, requires coagulation to provide economy of filtration through diatomaceous silica as well as an additional safeguard against contamination. Although the basic need may not be as great with diatomaceous silica, the degree of coagulation demanded is actually greater than with sand. Incomplete coagulation may be completed in a sand filter, in which the voids of the filter act as repositories for floc formed within the filter. Diatomite filters contain little space for floc storage, however, and incomplete preparation of applied water results in plugged filters, production loss and material waste. Poor coagulation may be tolerated by sand filters at the sacrifice of sanitary safety, but in diatomite filters it retards production. Interference with production produces a healthy demand for the greatest filterability in the applied water.

Literature

Baker's review of the history of water treatment led Wolman to comment that it is "largely a history of empiricism . . . an art and not a science" (3).

Fuller's monumental report (4) on studies at Louisville, however, may be regarded as the starting point for hundreds of investigations into the theory and practice of coagulation.

Fuller observed and described phenomena which were then unknown and unnamed. He reported that equal increments of alum added to water do not produce equal increments of coagulation, thereby calling attention to the isoelectric point. He referred to adsorption, which he called absorption for want of a better name. The difference in alum demand of various clay turbidities which he mentions seems to foreshadow ion-exchange properties recently studied by Langelier and Ludwig (5). He investigated at least eight iron and aluminum coagulant salts as well as the operation of an electrolytic cell as the source of hydrous oxides. He thereby directed attention to the problems and available tools when pH and the properties of colloidal solutions were unknown, plotting the course of coagulation studies for several decades. The physical—especially the colloid—chemists have added a wealth of material applicable to water coagulation. Perhaps the best summary of the progress of science in coagulation is contained in the chapter on "Coagulants and Coagulation" of *Water Quality and Treatment* (6), including the bibliography. This book also indicates the variety of selections, combinations, utilization methods and controls of coagulants.

Modern Coagulation Theory

The turbidity and color which are found in natural waters, and which it is the purpose of coagulation to remove, are colloids in suspension. Colloids owe their existence and stability to the presence of like electric charges on the particles. Neutralization of these charges, which are mutually repellent, permits agglomeration of the particles by collision and their retention by surface forces. Precipitation follows, in accordance with Stokes' Law, and with the aid of mechanical devices. This simplified statement indicates how the answers to coagulation problems may be sought.

The need for trial treatments or "jar tests" to determine optimum coagulant dosages and pH continues as a sign of the absence of a definitive measurement capable of showing what is needed or what has been accomplished. Norcom and Brown (7) state that: "A new problem of coagulation is presented to the operator every time there is an appreciable change in the raw water."

Whatever the choice of method, however, the purpose remains the same. The basic tools for coagulation treatments are oppositely charged suspensoids plus cations and anions, among which are hydrogen and hydroxyl ions. In fixed installations, the treatment practice is tailored to fit needs of the individual supplies, but such freedom of deliberation and choice is not practical in military purification. Ammonia alum and soda ash, which have been relied on for all field water treatment, are often not a perfect combination. For even mediocre results, they require flocculation tests, determination of optimum pH and far more vigilance than can ordinarily be accorded.

Military Purification

Some of the essential characteristics of military water purification in the field are:

1. Production of safe and potable water with minimum technical skill and supervision, regardless of ordinary variations in raw water

2. Minimum manpower requirements for operation and maintenance

3. Easily transportable equipment and supplies.

Minimum technical skill and supervision eliminate most methods to meet varying conditions of raw water that are current in fixed installations. Methods and equipment must be capable of coping with all possible field conditions. Adjustments are limited to single variables, dictated by simple observations. The need for a flocculation kit for trial treatments and pH comparators for routine operation is objectionable and burdensome under military conditions.

Minimum manpower is almost as important. Manpower is the most expensive item of field water purification because of the small capacities of the operating units and the high cost of operators. Ten thousand gallons of water produced in the combat zone by a 15-gpm. set may require 20 lb. of chemicals and other treatment supplies and 40 lb. of fuel for pumping. The set will assuredly require manpower costing at least $100. It is therefore essential to reduce both the extent of work and the motions connected with operation and maintenance of the equipment.

Easy transportability is another aspect of economy. Long hauls may double or triple total production costs. For economical operation of field water supply, distribution—usually the major cost—must be reduced to a minimum. The producing unit must be kept close to the consumer, who may be expected to move frequently and rapidly.

The essentials of civilian water supply practice are distorted beyond recognition in the military application. A fixed installation need not handle any and all kinds of water without change of method under reasonable supervision. Transportability, by definition, is foreign to a fixed installation. The difference which must be emphasized most, however, is the cost of manpower per unit of production. In the field, labor cost per gallon of water produced is approximately 1,000 times that at fixed civilian installations. The man required to produce 1 mgd. of water in civilian practice will do well to produce 10,000 gpd. in a combat area with field equipment, and it will cost ten times as much to keep him on the job. Equipment and supplies are insignificant in comparison with this factor.

These are some of the facts which have made it necessary to look again at the basic principles of coagulation as well as their application.

Research

Research aimed at basic principles and their application was undertaken in 1947 by New York University under a contract with the Corps of Engineers through the Engineer Research and Development Laboratories. Results of these studies were reported by the contractor in two reports dated August 2, 1948, and October 1, 1949. The ultimate objective of this research was improvement and simplification in preparing water for filtration in the field. A broad review (8) of the literature was made, and a bibliography of 141 items, dealing chiefly with theoretical aspects, was included.

The effect of a group of electrolytes —including calcium sulfate, magnesium sulfate, sodium sulfate, ammonium sulfate, disodium hydrogen phosphate, calcium chloride, calcium bicarbonate and sodium chloride—upon coagulation with aluminum and ferric salts and with bentonite clay suspensions, in pH ranges from 3.0 to 10.0, was studied. The relative effectiveness of the salts

in promoting aluminum and ferric flocculation in the zone below pH 7.5 was found to depend upon the anions, which are rated in the order: PO_4^{---}, SO_4^{--}, Cl^-, HCO_3^-. The rating was made in the absence of negatively charged turbidity sols. The relative desirability of the cations under the same conditions was rated as Na^+, NH_4^+, Mg^{++}, Ca^{++}. It was found that strong cations tend to peptize the hydrous oxide floc in the positive acid zone. In the pH zone above 7.5, the preferential positions of both cations and anions is reversed, especially if a negatively charged suspensoid such as bentonite clay is introduced. A trivalent or divalent anion in the alkaline negative zone peptizes the sol, whereas a strong cation assists coagulation.

The information, which is consonant with the findings of such other investigators as Bartow and Peterson (9) and Bartow, Black and Sansbury (10) is especially valuable in perfecting coagulation at fixed installations at which a clear picture of the character and behavior of raw and treated water can be obtained by suitable tests. Random addition of any one of these salts in field water treatment, however, would be unsound, and, on the other hand, the task of selecting the proper salt for a particular water would be difficult and impractical.

Exploratory jar tests made on several waters in the vicinity of Fort Belvoir gave disappointing results even when dissolved minerals present were very low. This experience recalls observations of Baylis (11) that the amount of dissolved silica present in most natural waters tends to invalidate conclusions drawn from the addition of electrolytes to silica-free distilled water. It appears that silica itself furnishes an example of the coagulating effect of a strongly adsorbed negative sol or polivalent anion upon positively charged floc or cations. Conversely, the tendency of silica to stabilize suspensoids in the alkaline zone of high pH has been observed and reported (12). It must be concluded that various electrolytes as well as artificial sols provide tools capable of improving coagulation but that they are also capable of causing interference or negative effects.

Use of Calcium Carbonate

Solid calcium carbonate was found to possess unique properties in promoting isoelectric conditions which may have been overlooked in the New York University studies. In those studies, calcium bicarbonate solution had been prepared and measured quantities were transferred to test beakers in which pH was manipulated over a broad range by the use of hydrochloric acid or sodium hydroxide. The zone of rapid flocculation was broadened by the addition of the calcium bicarbonate as it was by other electrolytes. The unique feature of the solid calcium carbonate is that it produces the pH in which the calcium and bicarbonate ions promote flocculation. Protection against too wide a swing to the high pH side is afforded by the low solubility product of calcium carbonate and the decreasing rate of solution as this value is approached.

Calcium carbonate as whiting or as pulverized limestone has been used for a long time in at least one water purification plant. According to Flentje (13), the Warren plant of the Bristol Water Co. had been using this material for a number of years before 1928 and had found it more satisfactory than either soda ash or lime in correcting acidity. During certain seasons, soda ash or lime tended to peptize the color and shorten filter runs to as little as

one or two hours; limestone increased them to seven or eight hours. Other plants which have used limestone are Gloversville and Ossining, N.Y., and it has produced very satisfactory results at both plants.* The limestone was applied to the water under treatment according to the need, presumably as shown by pH or alkalinity determinations.

Engineer Research

Limestone as a coagulant aid was first investigated by the water supply branch of the Engineer Research and Development Laboratories at Gunston Cove on the Potomac River during the period July–December 1949. Daily operations were carried on by the project engineer with one or more assistants. Tanks, pumps, filters and accessory parts of Army Water Purification Set No. 2 were used in quasi-field operation procedure modified for experimental purposes and quantitative data collection. Comparative coagulation tests were made with and without limestone to determine the behavior of the material, the method of application and the advantages. These tests were mainly batch treatments. The results were usually measured by testing the turbidities of the coagulated waters following standardized periods of mixing and subsidence. Filtration was ordinarily omitted for simplicity, and 343 batches were treated to compare several different coagulants. Potomac River water, subject to fluctuations of turbidity caused by variable rainfall and runoff, wind and tide, was used. The main channel of the river bypasses Gunston Cove and permits some subsidence of the natural turbidity of the stream, modified, however, by local showers and disturbances. During these tests the raw water contained continual blooms of common algae such as *Anabaena, Aphanizomenon* and *Microcystis*. Turbidity values varied between 28 and 154 ppm. The raw water had sufficient alkalinity and pH for the requirements of coagulation and was thus typical of many surface waters.

Mechanical Procedure

Coagulation equipment for the tests consisted of cylindrical, fabric tanks of 66-in. diameter and 36-in. depth, with a working capacity of 500 gal.; gasoline-engine-driven pumps of 30-gpm. capacity at low head; $1\frac{1}{4}$-in. diameter suction and discharge hose; and small wire screen coagulant baskets to hold lumps of coagulant or pellets of soda ash in the raw water stream during tank filling. The basket feeder is suitable for feeding the relatively slow-dissolving ammonia alum or soda ash pellets in ordinary field practice, but not for quantitative predetermined dosing or comparative purposes. Neither can it be used for more soluble coagulants such as ferric chloride. For tests involving comparisons of coagulants or procedures, solution feeders were rigged on the Mariotte bottle principle to deliver drops at a constant rate, thus providing the necessary dosage control.

In making the comparisons, two pumps were used in parallel, delivering water through rotameters at the desired rate to similar tanks. The filling time, during which chemicals were applied, was theoretically $16\frac{2}{3}$ minutes at the usual 30-gpm. rate. Filling the tank set up a rotation of its contents that was permitted to subside during the next 15 minutes, after which the coagulated water was sampled and

* Private communications from Harold C. Chandler, Albany, N.Y., and Thomas M. Riddick, Cons. Engr. and Chemist, New York, N.Y.

tested for pH, alkalinity and turbidity. The settling period was somewhat shorter than is available with the equipment in practice, but it was desirable not only to speed up data collection, but also to accentuate differences in the settling quality of the floc.

Rules and Precautions

Throughout the tests at Gunston Cove, although there was no obvious need to increase alkalinity or pH, the use of limestone was found to improve coagulation. The rules and precautions for its use are extremely simple. The limestone must be pulverized so that more than 90 per cent will pass through a 100-mesh sieve, and the balance through a 60-mesh sieve. The effect of limestone quality was not studied, but several brands, differing somewhat in size and composition, were used without any apparent difference in results. Much of the material was from stocks sold for agricultural use. It is not advantageous to use a fine powder such as precipitated chalk. The upper limit of particle size appears to be set by the necessity to keep the material in suspension with reasonable agitation. Sufficient agitation must be provided to keep the limestone and the floc or sludge in suspension during the coagulant dosing and mixing period. In some of the early tests, insufficient scouring velocities at the bottom of the tanks permitted limestone to settle without accomplishing its purpose.

Dosage Method

The method of dosage involves starting with a charge of 240 ppm. or more and maintaining such a surplus if the limestone is needed. In fill-and-draw procedure, the unused limestone and the sludge produced remain in the tank to be picked up in successive treatments. Doses of 1 or 2 lb. in a 500-gal. tank were equally effective. A 2-lb. dose will obviously last longer than the 1-lb. dose, but not twice as long.

The function of limestone in the Gunston Cove tests was principally physical. A similar effect was obtained in batch treatment by accumulating sludge from batch to batch until four or five had been treated. Starting with a clean tank and raw water of 48 ppm. alkalinity, 98 ppm. turbidity and a pH of 7.4, treatment with 39 ppm. of ammonia alum produced turbidities of 31, 27, 25 and 22 in four successive fillings, retaining the sludge each time.

In another clean tank to which 1 lb. of limestone was added, the same raw water and coagulant in parallel tests produced turbidities of 18, 18, 19 and 18. The pH of the limestone tank effluent was 7.1, alkalinity 49. The pH of the effluent without limestone was 6.9, alkalinity 37. A third group of four batches, using precipitated calcium carbonate, yielded turbidities of 29, 25, 21, 20. The pH was 7.7 and the alkalinity 65. A fourth group for which a tank containing sludge from twenty previous fillings was used gave turbidities of 20, 19, 21 and 20. The better results with the limestone in these tests appear to have been due principally to the physical effects of a mass of suitable suspended solids inasmuch as accumulated sludge was almost as effective as pulverized limestone.

Limestone also prevented the tendency of sunlight, algae and rising temperature to produce floating floc. This buoyant tendency is particularly troublesome in small, shallow basins, but undoubtedly plays a role in larger ones too. Floc particles carry gas bubbles which may be the results of supersaturation of the water with air as the temperature rises, or they may be due

to supersaturation with oxygen produced by photosynthetic algae. At midday—the effect is seldom seen in the early morning or late afternoon—the floc may settle normally at first and then rise to the surface. It was repeatedly observed that the limestone-treated tanks were less likely to suffer this floc turnover than nontreated tanks. The former are relatively immune, due possibly to a catalytic release of air via the limestone particles during the mixing, or to partial exclusion of light from the algae cells by the inert solids.

Comparison of Coagulants

Some comparisons of coagulants were made with interesting results. When the coagulants were used in molar equivalent doses, the results were very similar. A series of nine batches in which 58 ppm. of filter alum was used yielded an average turbidity of 11.1 ppm. Using the equivalent dose of ammonia alum in nine batches, gave 12.0 ppm. turbidity. With the equivalent ferric chloride dose, 10.0 ppm. turbidity resulted. It appears that ferric chloride is slightly better, but there is no indication whether the advantage is attributable to the cation or to the anion.

A further comparison of two more batches with each coagulant gave turbidity results of 9.3 with filter alum, 8.0 with ammonium alum, 6.3 with ferric chloride, and 5.8 with equivalent aluminum chloride. These last tests suggest that the choice of coagulant anion is more important than the choice between iron and aluminum in the environment of the limestone. This interpretation agrees with the theory that the limestone raises the pH into the zone in which a weak anion such as Cl^- is preferable to a strong anion such as SO_4^{--}.

Influence of Pulverized Limestone

Pulverized limestone has a marked steadying influence upon coagulation. This influence was more apparent to the operators than can be shown by statistical data. Good results could be duplicated at random without reference to pH, moderate turbidity changes or minor disturbing factors such as sunshine, wind or temperature changes. Overdosing or underdosing with coagulant did not produce complete failures such as otherwise occur. This excellent behavior led to an investigation of the feasibility of continuous flow treatment as compared with the batch method heretofore considered most suitable for field use.

Continuous treatment with limestone, using tanks and accessories that are practical or available for field use, seemed to call for some application of the suspended solids contact principle. A simple funnel was therefore constructed. It had a diameter of 5 ft. at the top, slightly less than that of the fabric tank, and approximately 13½ in. at the bottom. This funnel was made of sheet aluminum and suspended in the tank by means of lugs resting on the side staves. The apex of the funnel was just above the bottom of the tank to permit entrance of treated water. The effluent water was taken off through a small central launder at the top. Because mechanical agitation was not readily available, motion of the tank contents outside the funnel was obtained from the incoming raw water stream introduced in a manner similar to batch treatment except that the rate of flow and the nozzle size were reduced. Coagulant application was the same as in the batch process.

This primitive equipment had a number of defects, but it showed whether the suspended solids contact principle

was practicable for field use. After a brief period of adjustment and acquaintance, a comparison was made between the continuous and batch treatment methods using both according to the best technics developed.

Comparison of Methods

The comparison covered a five-day period in which production during the working hours was maintained as closely as possible at 15 gpm., the rated capacity of the prototype unit. As the production of a diatomite filter is extremely sensitive to water quality, all water after coagulation and settling was filtered through diatomite filters operating continuously at rated capacity. The criterion of performance was the filterability of the settled water.

Each plant, including coagulation and filtration equipment, was run by a single operator, who collected neither samples nor data. Every effort was made to maintain fair and impartial conditions. The operators were highly skilled and conscientious. To compensate for possible differences in pumps, engines, filters and personnel, the plants were switched at midpoint in the tests to the opposite process. Rather complete chemical, bacteriological and operating data were collected by a half-dozen collaborators who took no other part in the operations. The operations were observed and recorded by a temporarily assigned, disinterested expert. As the analytical data show no significant differences in the quantity or quality of the settled or filtered water from the two plants, all data are omitted.

Statistical Comparison

Statistically the two processes are approximately equal. Raw water pumpage used more gasoline in the continuous process because the rate was throttled to about 16 gpm. as compared with 30 gpm. in the batch process, whereas the filtered water pump used 10 per cent less gasoline in the continuous process. Three treatment tanks were used in the batch plant and the mean actual detention time was 60 minutes. One treatment tank was used in the continuous plant and the theoretical detention was 33 minutes of which approximately 10 were in the conical upflow compartment. A second tank was required for use as a wet well, but no reduction in turbidity occurred in this tank.

The demands on the operator's time were excessive for the batch process, with approximately six times the number of motions required for the coagulation operation. His entire day was occupied, whereas the continuous plant operator had periods of leisure. The continuous process could not have been operated as efficiently without the use of pulverized limestone, which was added as a corrective whenever the appearance of the suspended blanket suggested the need. Both processes were producing better water during the test than conventional scale plants ordinarily do.

Need for Alkaline Buffer

In the Gunston Cove tests there was no definite need for an alkaline buffer to neutralize coagulant acid. This requirement is found in some of the swamp waters of tidewater Virginia such as Miller's Pond at Camp A. P. Hill. The purification equipment was accordingly set up at the site and operated through a number of comparative cycles with and without limestone. The raw water during these tests had a total alkalinity of 9–10 ppm., pH of 6.4–6.8, total color of 95–105 ppm. and temperature of 78°F.

The data show that alkalinity can be supplied conveniently and effectively by a surplus charge of limestone which can be reinforced as required. The pH was raised from less than 4.3 to a maximum of 6.9. The apparent color of the settled water was higher when ferric chloride was used, but this may have been partly because of the color of residual iron floc.

Using ferric chloride in a series of eight batches, which were filtered immediately after subsidence, gave the following average results: alkalinity 12 ppm., pH 5.9, settled color 66 ppm., filtered color 13 ppm. It is concluded that this colored water presents no problem in coagulation with limestone and either ferric or aluminum coagulants.

Limestone Field Tests

To extend and establish the more general applicability of limestone, the same equipment was used in treatment and filtration of five scattered water supplies. From two to six batches were treated at each point. One of the objectives of this series was to determine whether familiarity with the supply was affecting the success of the treatment. Less than four hours was spent at each treatment point.

Treatment A was effected by placing 1 lb. of pulverized limestone in a 500-gal. fabric tank and filling the tank at a rate of approximately 35 gpm. while suspending a small quantity of ammonia alum in a wire basket inside the tank. Treatment B omitted limestone and substituted soda ash in the form of pellets contained in a second wire basket.

Filtration began 30 minutes after the start of filling or 15 minutes after filling was complete, whichever was longer. A small diatomite filter was used to measure filterability of the treated water. A thin precoat and no slurry feed was used to emphasize deficiencies in the quality of the treated water. Both the filter capacity and effluent quality were penalized by this method, which was better for test purposes.

Summary of Field Tests

The five supplies field tested included two waters which would be classed as hard and three which were very soft. The hard waters would not ordinarily require soda ash. The limestone treatment always yielded the best filtered water, and, in four of the supplies, the suitability for filtration of the settled water was improved 50–100 per cent, as indicated by the quantity filtered within a 26-psi. limit. In the one exception, the hardness of the raw water was 325 ppm., and it is significant that the filtration suitability without limestone equalled the best of the limestone results. One must experience rapid setting up and operation of a series of water plants to appreciate the fatuity of any procedure based upon laboratory methods. Even if no improvement in quality or quantity of filtered water were obtained with limestone, it would still have the outstanding advantage that it tends to standardize treatment. Limestone can be added in large excess, retained in the tank between fillings and used until exhausted.

The use of pulverized limestone as an aid to coagulation was explored for more than a year during which turbid, algae-laden, colored, hard, soft and relatively pure waters were treated. Whenever comparisons were available, turbidity and color of the settled water generally improved if limestone was used. The filtered water was also better. Limestone accelerated coagulation and precipitation except in one water

which contained 342 ppm. hardness. Coagulation was as rapid in this water without limestone as when limestone was used, suggesting the importance of calcium or magnesium ions as being coordinate with adequate alkalinity. Filterability was otherwise improved by limestone.

The most obvious advantages appeared in waters which lacked all of the components supplied by the limestone, such as suspended solids, alkalinity and strong cations. Even when these constituents were present in moderate quantities, as in Potomac River water, the limestone appeared to act as a catalyst capable of steadying the performance of suspended solids contact basins as well as intermittent batch treatments. More and better water can often be produced with the same equipment and personnel. The necessity for flocculation tests and pH determinations is reduced if not eliminated. Results assume a linear relation to coagulant dosage, and standardized treatment is more generally applicable.

Acknowledgments

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Geologic and Hydrologic Factors Affecting Perennial Yield of Aquifers

By V. T. Stringfield and H. H. Cooper Jr.

A paper presented on May 2, 1951, at the Annual Conference, Miami, by V. T. Stringfield, Geologist, U.S. Geological Survey, Washington, D.C., and H. H. Cooper Jr., Dist. Engr., U.S. Geological Survey, Tallahassee, Fla.

MORE than twenty years ago, in describing methods for estimating ground water supplies, Meinzer (1) stated: "The most urgent problems in ground water hydrology at present are those relating to the rate at which rock formations will supply water to wells in specific areas—not during a day, a month or a year, but perennially." This statement, of course, applies equally well to the present and the future. He referred to the safe yield of an underground reservoir as the practicable rate for withdrawing water perennially. In another report (2), he defined the safe yield as "the rate at which water can be withdrawn for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible." In a broader sense, the safe yield of a ground water reservoir may be considered the maximum rate at which ground water may be withdrawn without depleting the supply or harming either the reservoir or the quality of the water.

Some of the geologic and hydrologic factors that affect the yield of ground water reservoirs are: type, composition, structure, size and extent of the reservoir, recharge to and discharge from the reservoir, transmissibility and storage capacity of the reservoir, water temperature and the encroachment of salty or other water that will contaminate the supply or ruin the reservoir.

Some of the methods used in the investigation of the factors governing yield of ground water reservoirs resemble those used in studying surface reservoirs. In both ground and surface water studies it is necessary to measure the size and extent of the reservoir, rate of inflow and discharge, or to estimate these rates by determining changes in storage. For ground water studies, all available methods that may be applicable are generally used to make periodic inventories of the water from its entrance into the area as precipitation, stream flow or underground percolation, and its exit as evaporation, transpiration, runoff or underground leakage.

This discussion is based chiefly on the reports cited in the reference list. Published reports giving the results of many of the ground water investigations made in the United States up to 1946 are indexed in a bibliography compiled by Waring and Meinzer (3).

Aquifers

The geologic formations that constitute the ground water reservoirs and yield water to wells are usually known as water-bearing formations or aquifers. The geology may involve all kinds of rocks—igneous, sedimentary

and metamorphic—ranging in age from pre-Cambrian to Recent. It may involve every kind of rock structure. In some areas, ground water is held by faults in subterranean compartments; in others the faults or fault zones may serve as avenues of recharge or discharge. In some regions, dikes and veins may affect the occurrence and movement of the water significantly. The movement of the water may or may not be in accordance with the dip of the geologic formation. In some artesian aquifers, folded into anticlines and synclines, water may enter the aquifer on the flanks of an anticline, at sufficient altitude to move down-dip into the syncline and up-dip into the flank of an adjacent anticline. In others, such as those in central Florida, the direction of the movement of the water is not closely related to the geologic structure.

Under water table (nonartesian) conditions, aquifers function chiefly as reservoirs and under artesian conditions, chiefly as conduits in which water may move laterally many miles from the intake to the discharge areas. All aquifers serve as both reservoirs and conduits, however, and the two functions must be recognized and differentiated if the geologic and hydrologic factors that affect the safe yield are to be properly evaluated.

Recharge, Discharge and Storage

Aquifers are recharged by precipitation, stream flow and underground percolation. Discharge occurs as springs, seeps, underground leakage, evaporation and transpiration. If the water table is near the ground surface, water may be discharged by evaporation from the soil and transpiration from plants. In some arid regions, the evaporation and transpiration account for most of the discharge, and little or no water remains to form springs and seeps. In humid regions, although evaporation and transpiration may be great, as in Florida, there is generally sufficient recharge to form springs and seeps which feed the streams and maintain their flow during dry seasons.

Slight differences in geology may result in significant differences in the hydrologic properties of an aquifer. Two of these properties, the hydraulic permeability and the specific yield, are among the most important factors affecting the perennial yield. Hydraulic permeability, or perviousness of a rock, is its capacity for transmitting water under a hydraulic gradient. The quantity of water that will flow through a permeable formation is directly proportional to the cross-sectional area through which the water percolates, the hydraulic gradient and the coefficient of permeability, which is a constant that depends upon the character of the material. The quantity is inversely proportional to the viscosity of the water. The field coefficient of permeability (4, 5), as used by the U.S. Geological Survey, represents the quantity of water in gallons per day that will flow through a cross section of the aquifer 1 mile wide and 1 ft. thick, with a hydraulic gradient of 1 ft. per mile, at the prevailing temperature. Corrections for temperature must, of course, be made in comparing permeability in different areas and in laboratory tests. Temperature as a factor affecting the yield of ground water reservoirs is discussed elsewhere in this presentation.

Coefficient of Transmissibility

The field coefficient of permeability multiplied by the saturated thickness of the aquifer, in feet, may be defined as the coefficient of transmissibility (5), and represents the quantity of

water, in gallons per day, that will flow through a cross section of the aquifer 1 mile wide under a hydraulic gradient of 1 ft. per mile. An aquifer with a saturated thickness of 200 ft. and a coefficient of permeability of 500 would have a transmissibility of 100,000. In other words, a vertical section of the aquifer 1 mile wide with a hydraulic gradient of 1 ft. per mile would transmit 100,000 gpd. With a hydraulic gradient of 10 ft. per mile, it would transmit 1 mgd. With a cone of depression having a gradient of 100 ft. per mile at a certain distance from the well, the aquifer with a saturated thickness of 100 ft. and a coefficient of permeability of 500 would transmit, through a cylindrical section 1 mile in circumference, 5 mgd. (500 × 100 × 100).

Specific Yield

The specific yield (5, 6, 7) of an aquifer is the proportion of its volume that is occupied by water which it ultimately (7, 8) yields by gravity. For example, 100 cu.ft. of saturated material with a specific yield of 25 per cent will yield 25 cu.ft. of water when drained by gravity. The term "effective porosity" has been used by ground water investigators to mean approximately the same as specific yield. As recognized by Meinzer (6), students of agriculture prefer to use "effective porosity" in another way, and petroleum geologists use it in a more general sense. In ground water studies, however, the use of the term "porosity" instead of "effective porosity" may be misleading. A saturated clay which will yield little or no water to wells may have a higher porosity and contain more water than a productive water bearing sand, but its effective porosity or specific yield is much less than that of the sand. The specific yield indicates the storage capacity of nonartesian aquifers, which may be expressed as the coefficient of storage.

Coefficient of Storage

The coefficient of storage used by the U.S. Geological Survey (9) is the number of cubic feet of water released from storage in a saturated vertical column of the aquifer 1 ft. square when the water table (top of the zone of saturation) declines 1 ft. Under artesian conditions, the coefficient of storage (10) is the number of cubic feet of water released from storage in a vertical column of the aquifer 1 ft. square when the piezometric surface (the imaginary surface to which water levels in artesian wells will rise above a common datum) declines 1 ft.

In nonartesian aquifers, the coefficient of storage is much larger than in artesian aquifers, because water is drained from pores and interstices as the water table declines. Under artesian conditions, however, all pores and interstices remain saturated with water as the piezometric surface declines, and the aquifer releases water from storage only by contracting in proportion to its volumetric compressibility as the artesian pressure decreases. An aquifer under water table conditions might have a coefficient of storage or specific yield of 0.25; lowering the water table 1 ft. in a cubic foot of material would release 0.25 cu.ft. of water from storage. Under artesian conditions, the aquifer might have a storage coefficient of 0.00025; lowering the piezometric surface 1 ft. would release 0.00025 cu.ft. of water from a vertical column of the aquifer 1 ft. square. This quantity may seem insignificant, but in an artesian aquifer extending over many square miles, it is appreciable.

As the rate of decline of water levels in wells in an aquifer from which water

is being withdrawn is most rapid if the capacity of the aquifer to release water from storage is small, water levels or shut-in pressures in wells that tap an artesian aquifer decline rapidly across wide areas, after the rate of withdrawal increases. In the artesian aquifer in the Savannah, Ga., area (11), large changes in rate of withdrawal caused measurable fluctuations in artesian pressure for approximately 17 miles, and wells even 25 miles away seemed to be affected.*

The amount of ground water discharged naturally from an aquifer not affected by wells is equal to that entering in the recharge area, except for temporary differences due to changes in the amount stored in the aquifer. The average discharge rate for a long period is approximately equal to the average recharge rate. Withdrawal of water from wells is balanced by a decrease in water in storage, a decrease in discharge, an increase in recharge, or a combination of these changes.

Water first withdrawn from wells is largely from storage, but as removal continues and the water table or piezometric surface declines, the withdrawal consists in increasing amounts, of water that would have been naturally discharged, or water that would have been rejected from recharge. When the effects of withdrawal reach the intake or recharge areas, the rate of recharge is increased if there is any rejected recharge prior to the development of wells.

Salvage or Capture

Water obtained through decrease in natural discharge and increase in recharge has been regarded as salvage (2, p. 120; 12). The word "salvage" may not be entirely satisfactory in such areas as the Southwest in which the natural discharge and rejected recharge would be used, if they did not enter the aquifer. Theis † has suggested that the word "capture" might be more appropriate in these areas. Water levels in wells in the area affected by increasing withdrawal of water will decline, and water will be withdrawn from storage until the salvage or capture rate equals the withdrawal rate. If the withdrawal continues to exceed the capture, however, the perennial yield will be exceeded, and water levels will decline persistently.

The time required for declining water levels to reach equilibrium or a steady state under a given rate of withdrawal, is more or less proportional to the coefficient of storage of the aquifer. After equilibrium conditions have been established, the extent and shape of the cone of depression in the water table or piezometric surface will be controlled partially by the capacity of the aquifer to transmit water and partially by the distance between the withdrawal area and the recharge or discharge areas.

Water Levels in Wells

Water levels in wells, and their fluctuations, give information essential to determining the yield of aquifers. The drawdown, or the lowering of water level in a pumped well, is usually limited in the development of an area.

In some localities, water may be withdrawn at a rate that exceeds the perennial yield, whereupon water levels will decline persistently, although the entire area may not be overdeveloped. The

* Private communication from M. A. Warren, Hydr. Engr., Ground Water Branch, Water Resources Div., U.S. Geol. Survey, Mineola, N.Y.

† Private communication from C. V. Theis, Dist. Geologist, Ground Water Branch, Water Resources Div., U.S. Geol. Survey, Albuquerque, N.M.

practical limit of drawdown of water levels in wells being pumped may also limit further withdrawal locally, although the perennial yield of the entire aquifer has not been exceeded. In the Snake River Plain in Idaho (13), large quantities of ground water are available, but the water table is 1,000 ft. below the land surface in places. The drawdown limit may sometimes be the bottom of the aquifer, but for many developments, the limit is the level at which pumping becomes too costly. Under these conditions, the problem may be solved by spacing wells more widely and by drawing upon portions of the region that are not overdeveloped—as at Alexandria, La., and Houston, Tex. Artificial recharge of the aquifers has often been effective in increasing the perennial yield.

Water Temperature

The influence of temperature on the viscosity of water is a factor in determining the rate of movement in an aquifer. Temperature is also important if water is to be used for cooling or heating. If water has a suitable temperature for cooling, any development that increases it, such as return of warm water through wells to the ground, as required on Long Island, N.Y., may be an important factor. If warm water supplies are used, as at Hot Springs, Ark., and Steamboat Springs, Nev., temperature is also one of the factors entering into safe yield.

Ground water temperature near the land surface fluctuates with changes in atmospheric temperature, but these fluctuations decrease rapidly within the first few feet of depth. At greater depths, the water has a higher temperature, corresponding to the temperature increase found with increasing depth in the earth. Temperature variations of ground water within a given area are generally not sufficient to be important in estimating the yield of an aquifer. In aquifers receiving a large amount of induced infiltration or recharge from a surface stream, however, as at Charleston, Ind. (14), variations in the temperature of water entering the aquifer cause sufficient variations in the water viscosity to affect the rate of ground water flow significantly, thereby affecting the yield of the aquifer considerably.

Salt Water Encroachment

In some areas, especially along seacoasts, aquifers may become contaminated with salty water if they are overdeveloped. This condition may occur from encroachment of salty water through exposures of the aquifer to salt water or through leaks between aquifers. Contamination may also occur through an encroachment of connate water (salty water in which the aquifer was deposited) or salty water that entered prior to recent time. Wells drilled too deep into salty water, or through salty aquifers, may contaminate an aquifer if they are not properly constructed and finished.

If salt water contamination may occur, withdrawal must be sufficiently limited to forestall salt water encroachment, or the water supply, and part of the aquifer, may be ruined.

Under natural conditions of aquifer exposure to salt water, contact between fresh and salt water will depend in part on the relation of the salt water head to the fresh water head. If the latter exceeds the former, fresh water discharges into the body of salt water. But if the salt water head is the greater, salt water will move into the aquifer until it balances the fresh water. This relation or principle of balance, sometimes called the theory of Ghyben and Herzberg, is shown in Fig. 1. It may

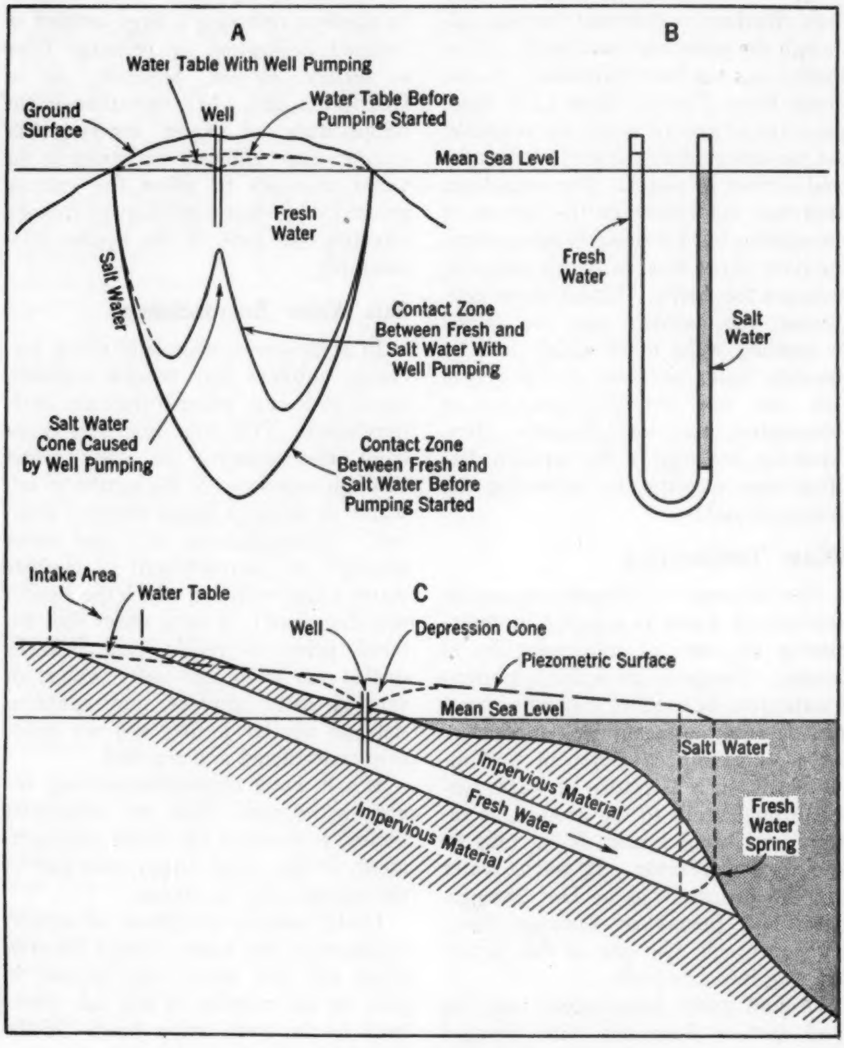


Fig. 1. General Relation Between Fresh and Salt Water

A is a cross section of a small island or peninsula of permeable sand showing general relationship between fresh and salt water. B is a U-tube showing balance between fresh and salt water. C shows relation between fresh and salt water under artesian conditions.

be represented algebraically (15, 16) as follows:

If H is the total thickness of fresh water, h the depth of fresh water below sea level and t the height of fresh water above sea level, then:

$$H = h + t$$

But the column of fresh water (H) must be balanced by a column of salt water (h) to maintain equilibrium. Therefore, if g is the specific gravity of sea water and that of fresh water is 1:

$$H = h + t = hg$$

From which:

$$h = \frac{t}{g - 1}$$

The difference in specific gravities between fresh water and salt water will be $g - 1$.

With 1.025 as the specific gravity of sea water, salt water would be displaced by fresh water to 40 ft. below sea level for each foot of head of fresh water above sea level. In both nonartesian and artesian aquifers, the balance between salt and fresh water may be compared with that of two liquids of different specific gravities in a U-tube. The well and aquifer form one side, and the column of salt water to which the aquifer is exposed forms the other. The simple relation between the salt water and fresh becomes complicated if rapid movement is involved

The thickness of an aquifer, fresh water head and maximum depth at which it is exposed to salt water are important factors in salt water encroachment. If a horizontal aquifer 100 ft. thick on the sea coast, underlaid with impervious beds and with a fresh water head of 10 ft. above sea level at the submarine outcrop, were exposed to the salt water at a maximum depth of 200 ft., the fresh water head (assuming the specific gravity of the sea water to be 1.025) would balance a 400-ft. column of salt water (10 × 40). Fresh water would therefore discharge at the submarine outcrop at which the maximum column of salt water is 200 ft. With a freshwater head of not less than 5 ft. above sea level along the coast, a nearby well would be in no danger of sea water encroachment, regardless of the drawdown. If withdrawal of water lowered the head to 2 ft. above sea level, only enough head would exist to prevent encroachment in the aquifer to 80 (2 × 40) ft.—salt water would move into the aquifer below that level.

Southern Atlantic Coastal Plain

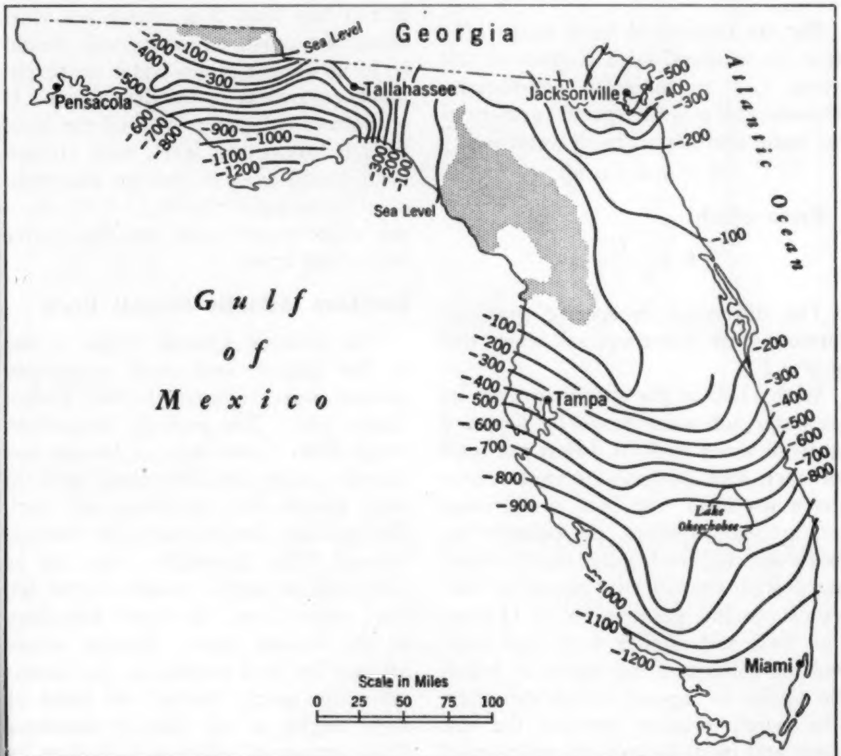
The Atlantic Coastal Plain is one of the largest and most productive ground water sources in the United States (6). The geologic formations range from Cretaceous to Recent and consist chiefly of alternating beds of sand, gravel, clay, limestone and marl. The geologic formations in the Atlantic Coastal Plain generally crop out as belts approximately parallel to the fall line which forms the inner boundary of the coastal plain. Except where affected by local structures, the formations dip gently toward the coast at right angles to the belt of outcrops. This pattern of outcrops is broken by such local geologic structures as the Ocala arch in Florida and the Cape Fear arch in North Carolina.

The Cretaceous formations underlie most of the region and form the inner belt of outcrops. The top of the Cretaceous is indicated approximately by contour lines on a tectonic map of the United States (17). In North and South Carolina, the contours representing the top of the Cretaceous are

subject to considerable revision, but revised contours are shown on an unpublished ground water map prepared by the U.S. Geological Survey.

The sands of Cretaceous formations are important sources of water, both artesian and nonartesian, except along the Georgia and Florida coasts, along which the formations are buried deeply, usually containing water of poor quality.

A 2,830-ft. well at Parris Island, S.C., passed through salty water and reached fresh water in the Cretaceous aquifer. The extent of this fresh water zone along the coast is not known, but judging from available well records, one would not expect fresh water to be present in the Cretaceous south of Savannah, Ga.



Courtesy David B. Erickson

Fig. 2. Structure Contour Map of Florida and Southern Georgia

The contour lines indicate the levels of the top of the Ocala limestone with reference to sea level at intervals of 100 ft. The stippled areas are those regions in which the Ocala limestone is at or near the surface of the earth.

Formations ranging in age from Paleocene to Recent overlie the Cretaceous formations and supply water to wells throughout much of the region. The formations are predominantly limestone, marl and sand in both Florida

and southeastern Georgia, where Eocene, Oligocene and Miocene limestones form the principal artesian aquifer. Formations ranging in age from Miocene to Recent, consisting mainly of limestone, shell marl and sand, are also an important source of water.

The principal artesian aquifer in Florida and southeastern Georgia consists of the Ocala and associated Eocene limestones together with the overlying Tampa limestone of Miocene age, which act as a hydrologic unit of from a few feet to more than 500 ft. in thickness. In some places, Oligocene limestone is present. The name Floridan has been proposed by Parker (18) for the aquifer. Figure 2 shows the top of the Ocala limestone, which approximates the top of the aquifer in Florida.

Although most of the work by the U.S. Geological Survey in cooperation with the Florida Geological Survey and the Georgia Dept. of Mines, Mining and Geology on the perennial yield of the aquifer has been in such local areas as Orlando, Sarasota, Jacksonville and Fernandina in Florida, and Savannah in Georgia, some regional work has been done. This work includes the preparation of a map of the piezometric surface of the artesian water, which represents the height to which water will rise above a given datum in tightly cased wells that penetrate the aquifer (Fig. 3). The contours show the direction of movement of the water and indicate the areas in which surface water enters the aquifer and those in which water is discharged from the aquifer. Among the most significant features are the relatively high areas of the piezometric surface such as the lake region in southcentral Florida, indicating recharge of the aquifer, and the low areas indicating discharge from the aquifer. Before the piezometric surface was mapped, available information indicated that the aquifer was recharged only where it was at or near the surface, as shown by the area in which the Ocala limestone crops out (Fig. 2). A 1931 investigation in Sarasota County (19), however, showed that the artesian water in that county moves westward, indicating a recharge area east or northeast of the county. After the regional piezometric surface was mapped (20), it was evident that the aquifer is recharged east of Sarasota County in several large areas in the lake region of the Florida peninsula (20) and in Georgia (11), although the aquifer is overlain by as much as several hundred feet of the Hawthorn Miocene formation, which includes relatively impervious beds.

The geologic studies of the ground water showed that the numerous lakes in the recharge areas occupy sinkholes filled with permeable sands, which extend to the aquifer and permit water from the surface to percolate to it. Another significant feature of the map is its indication that the intake, movement and discharge of the artesian water are in part independent of the major structural features of the area. In southcentral Florida where the aquifer dips southward on the flank of the Ocala dome, the artesian water moves radially from the recharge area and consequently not in the same direction as the dip of the aquifer.

More detailed maps (21) of the piezometric surface in local areas show significant differences in the transmissibility of the aquifer. The shape of the piezometric surface, together with the quantity of water taken from wells in Savannah, Brunswick, Fernandina and Jacksonville, show that the transmissibility is much greater at Brunswick and Jacksonville than at Savannah and Fernandina.

Fig. 3. Piezometric Surface of Artesian Water in Florida and Southeastern Georgia

The contour lines represent the approximate height, in feet, to which water will rise with reference to mean sea level in tightly cased wells that penetrate the principal artesian aquifer. The contour lines are at intervals of 20 ft.

The artesian aquifer crops out in the Atlantic Ocean and in the Gulf of Mexico. Under these conditions, the factor limiting safe yield in some places along the coast may be the relation between the sea water and the fresh water in the aquifer. Figure 2 shows that the top of the aquifer on the west coast of Florida is at or near sea level north of Sarasota County. On the east coast, it is as much as 1,000 ft. below sea level at Miami, and only 200 ft.

below near St. Augustine. Between St. Augustine and Savannah it is as much as 500 ft. below sea level, and northeast of Savannah only approximately 200 ft. below. The shape of the piezometric surface shows that artesian water discharges into the Gulf and the Atlantic in areas in which the aquifer is less than about 200 ft. below sea level. In such places as the Atlantic coast southeast of St. Augustine and northeast of Savannah, water is discharged into the ocean near the shore, although the formation does not crop out. This situation prevails because the overlying confining beds of the Hawthorn formation are thin in these areas, and in some places, as at the submarine spring 2.5 miles east of Crescent Beach, the water rises through a sinkhole.

The geologic structure of the aquifer offshore is not known, but if it is similar to that along the coast, a projection of the formations would indicate that the aquifer crops out at different depths at the edge of the continental shelf, which is only about 15 miles east of the coast at Miami but as much as 100 miles east of the coast at Savannah. If the confining beds above the aquifer are sufficiently impervious, and the artesion head at the outcrop exceeds that of the column of salt water, discharge from the aquifer occurs. Along the east coast south of St. Augustine, salty water in which the limestone was deposited or sea water that entered the aquifer prior to Recent time has not been completely flushed from the aquifer, and, therefore, although there is discharge from the aquifer and the artesian head is sufficient to prevent encroachment of sea water at present, the artesian water may have a relatively highly chloride content. Areas of incomplete flushing are shown in Fig. 4.

If the aquifer is exposed to or contains salt water, overdevelopment may cause the salty water to move into the well field, as happened several years ago at Tampa and St. Petersburg. The problem at St. Petersburg was solved by Malcolm Pirnie, who selected a site for a new well field in an area free from danger of salt water encroachment.

Along the coast from Savannah, Ga., southward almost to St. Augustine, Fla., the aquifer is both overlain and underlain by confining beds that prevent salty water from moving either downward or upward into the aquifer. Under these conditions, salt water contamination would be expected only from: [1] leaky wells that penetrate salt water above or below the aquifer and [2] lateral encroachment of sea water if the artesian pressure is lowered sufficiently.

In localities in which withdrawal of water has formed a large cone of depression in the piezometric surface, as at Savannah, encroachment will occur if that cone extends to an area in which salt water is present in the formation. Since the movement of ground water is relatively slow, wells at some distance from contaminated areas may yield fresh water for a considerable time after the cone has extended to the contaminated areas.

Summary

The most urgent problems in development and use of ground water are those relating to the perennial yield of aquifers. Perennial yield is sometimes regarded as the safe yield or the maximum rate at which water may be withdrawn without depleting the supply or harming the aquifer or water quality.

Some of the geologic and hydrologic factors that affect the yield of aquifers are: type, composition, structure, size

and extent of the aquifer; recharge to and discharge from the aquifer; coefficients of transmissibility and storage; water temperature; potentiality of an encroachment of salty or other water that would contaminate the supply or ruin the aquifer.

properties of an aquifer may be found. Two of these properties are hydraulic permeability and specific yield.

Under water table (nonartesian) conditions, aquifers function chiefly as reservoirs, and under artesian conditions as conduits. The two functions must be recognized and differentiated if the geologic and hydrologic factors affecting the yield are to be properly evaluated.

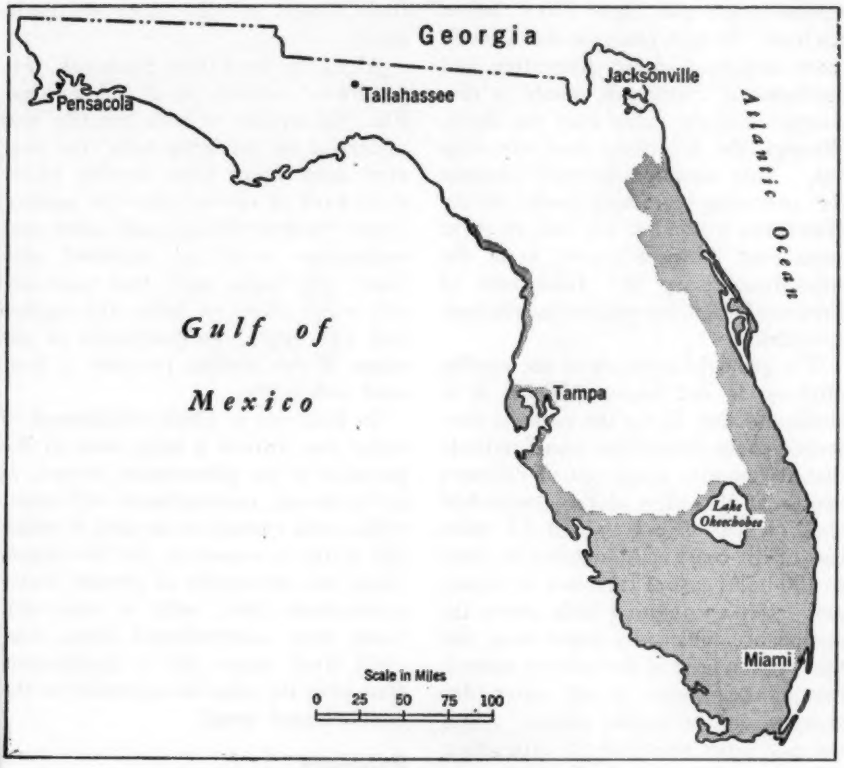


Fig. 4. Chloride in Artesian Water

Stippled areas show regions in which artesian water contains chloride content of more than 100 ppm. at moderate depths.

The geology of aquifers may involve all kinds of rocks—igneous, sedimentary and metamorphic—ranging in age from pre-Cambrian to Recent, and every kind of rock structure. With only slight differences in the geology, significant differences in the hydrologic

Aquifers are recharged by precipitation, stream flow and underground percolation. Discharge occurs as

springs, seeps, underground leakage, evaporation and transpiration. From an aquifer not affected by wells, the amount of ground water discharged naturally is equal to the amount entering it in the recharge area, except for temporary differences due to storage changes. Withdrawal of water from wells is balanced by a decrease in the amount of water in storage, a decrease in discharge, an increase in recharge or a combination of these.

Water that is first withdrawn from wells is largely from storage, but as withdrawal continues, and the water table or piezometric surface declines, the water withdrawn consists of increasing amounts that would have been discharged naturally or that would have been rejected from recharge. Water obtained through decrease in natural discharge and increase in recharge is regarded as capture. Water levels in wells in the area affected by increasing water withdrawal will decline, and water will continue to be withdrawn from storage until the rate of capture equals the withdrawal rate. If the withdrawal rate continues to exceed the capture rate, however, the perennial yield will be exceeded, and water levels will persistently decline until storage is used up.

In some areas, water may be withdrawn at a rate that exceeds the perennial yield and water levels will decline persistently, although the area as a whole has not been overdeveloped. The practical limit of drawdowns in wells being pumped may also prevent further withdrawal locally, although the perennial yield of the aquifer as a whole has not been exceeded. The ultimate drawdown limit may sometimes be the bottom of the aquifer, but there are many developments in which the limiting drawdown is the level beyond which pumping becomes too costly. The problem may then be solved by spacing wells more widely and drawing upon areas that have not been developed. Artificial recharge of the aquifers has also been effective in increasing the perennial yield.

In aquifers in which there is much induced infiltration or recharge from a surface stream, temperature variations cause sufficient changes in the viscosity of the water to have a significant effect on ground water flow rates.

In some areas, especially along seacoasts, aquifers may become contaminated with salty water if they are overdeveloped. If contamination occurs, the relation between salt and fresh water may be a limiting factor affecting the maximum withdrawal possible without causing salt water encroachment.

The principal artesian aquifer which underlies Florida and southeastern Georgia offers an illustration of geologic and hydrologic factors affecting the perennial yield. In that aquifer, the safe yield has been exceeded locally in only a few places in which overdevelopment has caused salt water encroachment, such as the old well field at St. Petersburg, Fla. Large quantities of water now discharged into the streams or the ocean may be salvaged by wells. With further development of the aquifer that would cause further lowering of the water levels in the recharge area, much of the water forming surface runoff or which is taken up by evaporation or transpiration would enter the aquifer and thus be salvaged by wells. Artificial recharge will sometimes increase the yield of this aquifer, which is one of the most productive ground water reservoirs in the world.

Acknowledgment

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Geologic and Hydrologic Factors in the Perennial Yield of the Biscayne Aquifer

By Garald G. Parker

A paper presented on May 2, 1951, at the Annual Conference, Miami, by Garald G. Parker, Senior Geologist, U. S. Geol. Survey, Washington, D.C.

THE two chief objectives of this report are: [1] to present a general overall view of the geology and hydrology basic to an understanding of water supply developments in the Miami area and [2] to discuss the factors of perennial yield that are applicable to the local aquifer.

The area under discussion, which is shown in Fig. 1, generally covers Dade County, Fla., with special emphasis on the eastern part along the Atlantic Coastal Ridge and the bordering margin of the Everglades. It is in this area that most of the Florida population lives and the water supplies are developed.

The climate is semitropical to tropical, with oceanic rather than continental characteristics. Rainfall averages approximately 60 in. a year, but annual departures from this figure may be rather large. The rainfall deficiency at Miami in 1944 was 29.19 in. and in 1945 was 34.54 in. Thus in two consecutive years, there was a total rainfall deficiency of 52.42 in., or almost an average year's precipitation. Rainfall, however, is very heavy in some years—being greatly in excess of the average.

The annual distribution of rainfall is not uniform in either time or place, but there is usually a dry season that lasts from November through April, and a wet season from May through October (Table 1). Rainfall ordinarily occurs as spot showers that may drench a very localized area of only a few square miles, or even only a few city blocks, and leave the surrounding area totally dry. The average annual temperature is approximately 75°F., and the prevailing winds are from the southeast. The humidity tends to be high, but so does the evaporation rate.

General Geologic Setting

The Miami area is a part of the eastern rim of the Everglades. It chiefly occupies a low limestone ridge that is nowhere higher than 22 ft. above sea level and averages approximately 8 ft. Surrounding this ridge to the east, south and west, is an ice age (Pleistocene) wave-cut terrace, the shoreline of which averages approximately 5 ft. above sea level. This terrace, the Silver Bluff (1, p. 24; 2; 3), is bordered at its inner margin in many places by a wave-notched scarp. Its development is readily observed in the low bluff northeast of Dinner Key, at which it parallels Bayshore Drive on the northwest side for approximately a mile.

The Floridian Plateau

Structurally, Florida appears to be a huge horst—a block-like feature

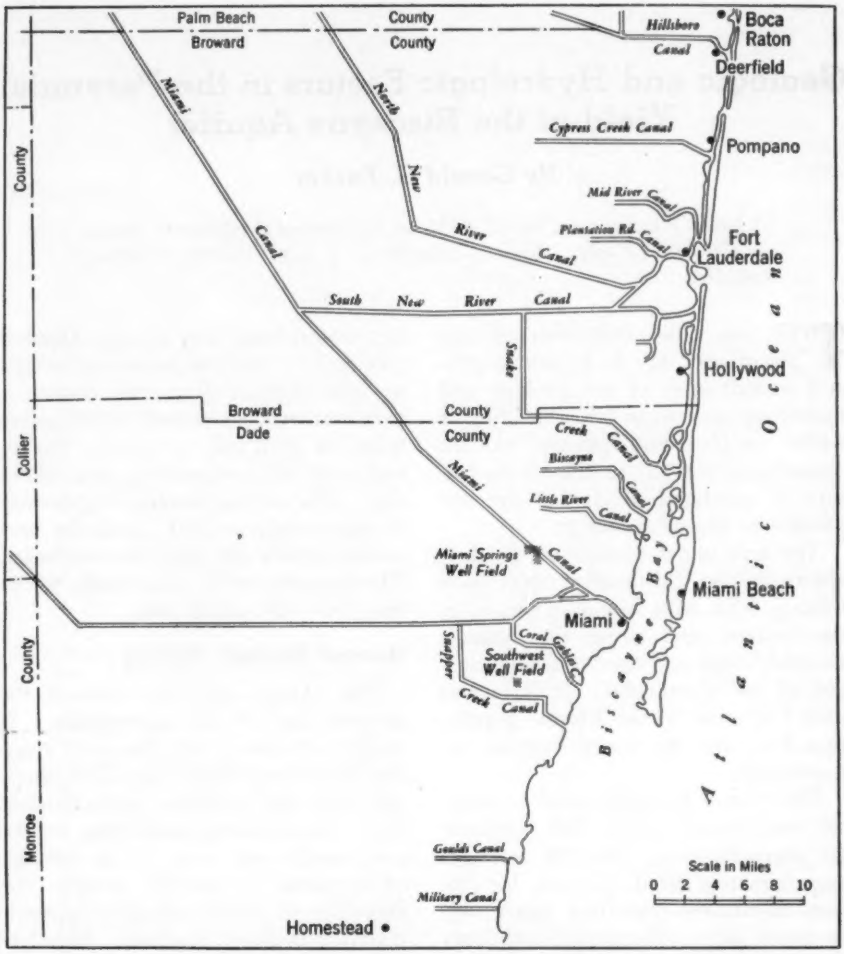

Fig. 1. Area of Report and Location of Miami's Municipal Well Fields

The well fields are indicated by the shaded area. Also shown are the canals located generally between Pompano and Homestead.

bounded on the east, south and possibly on the west by major zones of high angle faults along which large-scale down-dropping of the adjacent crust of the earth has taken place. This formation leaves the peninsula of Florida standing above the adjacent deep sea bottom much like a table stands above the floor. Vaughan (4) named this feature the Floridian Plateau, and speculated that its form is the result of some fold of the ocean bottom, perhaps in some way connected with the angle of the Piedmont area in central Georgia.

Pressler (5) mapped the location of faults involved in the structure on the east and south, and suggested (5, p. 1856) down-warping to account for the form of the plateau. The Floridian Plateau is not actually level but has been tilted slightly to the west so that now only the eastern half is above the sea, whereas the western portion slopes gently out under the shallow waters of the Gulf of Mexico for many miles.

TABLE 1

Monthly Precipitation and Temperature† Data for Miami, Fla.‡*

Month	Rainfall—*in.*			Avg. Temp. °*F.*
	Avg.	Max.	Min.	
Jan.	2.27	7.93	0.00	67.0
Feb.	2.03	5.91	Trace	68.0
Mar.	2.63	9.74	0.00	70.3
Apr.	3.41	10.75	0.10	73.9
May	7.15	18.66	0.94	77.2
June	7.17	25.34	0.70	80.0
July	5.60	15.22	2.48	81.8
Aug.	5.88	13.71	1.20	82.1
Sept.	8.65	20.35	2.08	79.9
Oct.	7.74	27.86	1.25	78.0
Nov.	3.26	17.72	0.10	72.5
Dec.	1.98	12.08	0.00	69.1
ANNUAL AVG.	57.79§	—	—	75.1

* Record continuous since 1855.
† Record continuous since 1895.
‡ U.S. Weather Bureau records.
§ Average for downtown Miami; for the Coastal Ridge an average value of 60 in. is used.

Structural Features—the Ocala Uplift

The principal geologic structure in the southern part of the state is the Ocala uplift, an elongated dome that trends northwest and plunges to the southeast (Fig. 2). As shown by Applin and Applin (6) and Pressler (5), the uplift involves chiefly limestones and dolomites, the ages of which range from Cretaceous to Oligocene.

At the top of the uplift, to 150 ft. above sea level, the Ocala limestone of Eocene age and the Suwannee limestone of Oligocene age are truncated by the land surface. In the latitude of Miami, the tops of these formations are approximately 1,200 and 900 ft. below sea level, respectively. The younger overlying beds of Miocene, Pliocene, and Pleistocene ages become progressively thicker toward the sea than at their outcrop areas on the flanks of the Ocala uplift. Because of the structure and the hydrologic characteristics of the rocks, artesian conditions exist in some of the formations, especially the older Tertiary ones. These formations mainly crop out on the ocean or gulf floors, or on the steeply dipping flanks of the Floridian Plateau.

Folding, widespread but minor faulting, differential compaction and truncation of beds on high parts of the uplift are the chief characteristics of the present structure of the Floridian Plateau.

Floridan Aquifer

Throughout much of Florida ground water supplies are obtained mainly from the artesian aquifer that is largely composed of the Ocala, Lake City, Avon Park, Suwannee and associated limestones. It has long been known as the principal artesian aquifer of the state (7) and in 1946 was named the Floridan aquifer (3). At Miami, it is buried under approximately 600 ft. of relatively impermeable material and contains only saline and corrosive waters.

Floridan Aquiclude

The term "aquiclude" was proposed by Tolman (8) to describe a forma-

tion that, although porous and capable of absorbing water slowly, will not transmit it quickly enough to furnish an appreciable supply for a well or spring. The term is used here to describe the thick and relatively impermeable blanket of materials of different ages and geologic formations that, as a unit, caps the Floridan aquifer.

feet. In the Miami area, the aquiclude is approximately 600 ft. thick and includes not only the Hawthorn formation but also the greater part of the Tamiami formation, which is here referred to as the upper Miocene.

Although composed of one or more geologic formations, the Floridan aquiclude is a unit containing water but

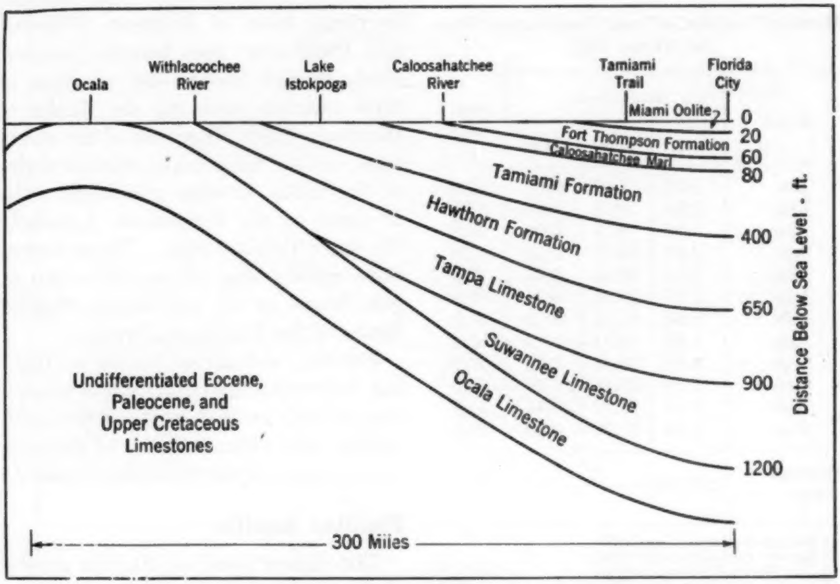

Fig. 2. Generalized North-South Cross Section of Florida

This cross section from the vicinity of Ocala to Florida City shows the structure and stratigraphy of southern Florida.

This blanket is composed principally of strata of clay, silt and marl with greater or smaller admixture of sand, fine gravel and shells. Wells ending in it have been entirely unproductive —"dusters" the drillers term them. Throughout most of its extent, the aquiclude is composed chiefly of the Hawthorn formation of middle and lower Miocene age and ranges in thickness from a few to several hundred

yielding little of it. It confines artesian water in the Floridan aquifer and supplies a relatively impermeable basement, or nearly watertight foundation, upon which the Biscayne aquifer rests.

Biscayne Aquifer

The name Biscayne aquifer is proposed for the hydrologic unit of water-bearing rocks that carries unconfined ground water in southeastern Florida.

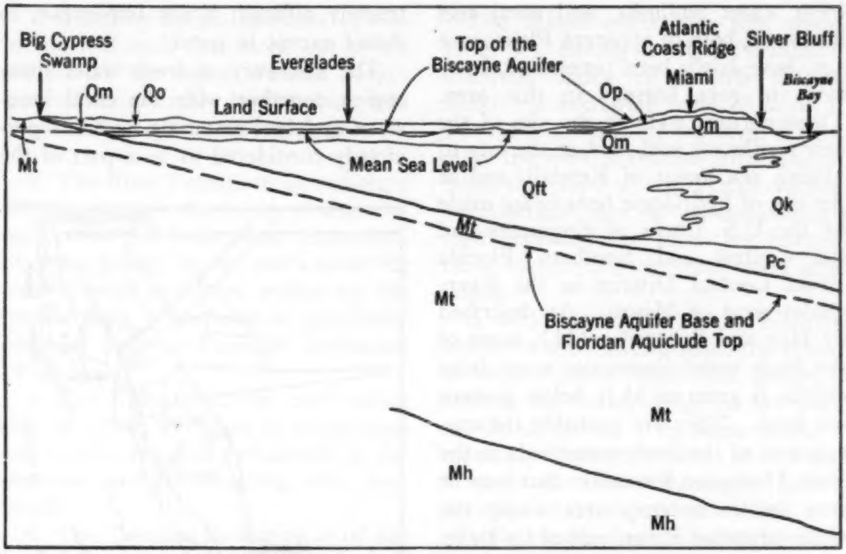

Fig. 3. Idealized East-West Cross Section of Miami Area

General relationships of geologic formations in the Miami area and the Biscayne aquifer are shown. The cross section was not drawn to scale. The horizontal distance is 30 miles, and the greatest vertical depth (to base of Biscayne aquifer) is 200 ft.

Key

Recent

Qo —Everglades soils including Lake Flirt marl at base

Pleistocene — Biscayne Aquifer Components

Op—Pamlico sand
Qm—Miami oolite
Qk —Key Largo limestone
Qft—Fort Thompson formation

Pliocene

Pc —Caloosahatchee marl
Mt—Tamiami formation (in part)

Miocene — Floridan Aquiclude Components

Mt—Tamiami formation (in part)
Mh—Hawthorn formation

It is most permeable and productive in eastern Dade and Broward Counties and in the southeastern part of Palm Beach County. It contains rocks ranging in age from upper Miocene through Pleistocene (Fig. 3). From its base upward, the aquifer includes, in one place or another, the permeable limestone of the Tamiami formation (Miocene) and parts or all of the following formations: the Caloosahatchee marl (Pliocene), the Fort Thompson formation (Pleistocene), the Miami oolite (Pleistocene), the Key Largo limestone (Pleistocene) and the Pamlico sand (Pleistocene).

Until recently, the bulk of rocks in the Biscayne aquifer was believed to belong to the Tamiami formation (9, 10). Beds of fresh water limestone, a few inches to approximately a foot thick, containing molds and casts of

fresh water mollusks, and coral reef limestone, both of apparent Pleistocene age, have lately been penetrated, however, in core borings in this area. These corings were at the site of the new southwest well field of the city of Miami, northwest of Kendall, and at the site of hydrologic tests being made by the U.S. Corps of Engineers and the Central and Southern Florida Flood Control District in the Everglades west of Miami. As described by Hoy and Schroeder (11), some of the fresh water limestones come from depths as great as 55 ft. below present sea level. They are probably the correlatives of the fresh water beds in the Fort Thompson formation that may be seen in its outcrop area along the Caloosahatchee River, east of La Belle. Parker (9) tentatively correlated these exposed fresh water limestone layers with low-level stands of the sea during glacial stages of the Pleistocene, and the intercalated marine beds with the high-level stands of the sea during the interglacial stages.

Well cuttings previously available for study have been from holes made by either cable-tool or jet rigs (percussion type drills). Such samples are so comminuted by bit action that recognition of the presence of either the coralline rock or the fresh water limestone is not possible. If fresh water limestone has been found in the cores, the limestone is either in the form of thin beds or shallow fillings in preexisting solution holes. It is evident that in samples of these materials taken by the percussion type rigs, the cuttings not only would be finely ground up, but also would be intimately mixed with cuttings from the overlying and underlying marine limestones and sands. They would therefore be extremely difficult, if not impossible, to detect except in cores.

The discovery of fresh water limestones, together with the coral limestone and reef materials, in rocks previously considered to be a part of the

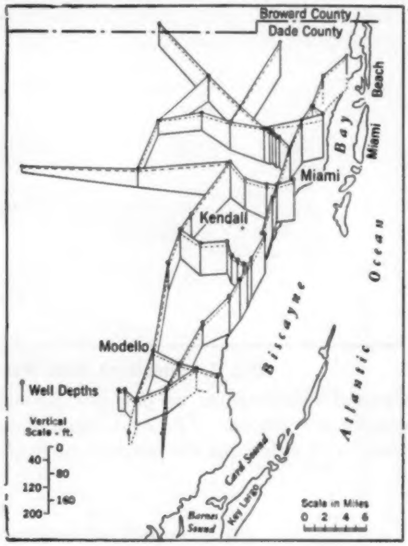

Fig. 4. Fence Diagram of Biscayne Aquifer

Geologic features of the Biscayne aquifer in Miami region are shown. Broken line represents mean sea level. The aquifer includes, from top to bottom, following formations: [1] *(Pleistocene) Pamlico sand, Miami oolite, Fort Thompson formation and Key Largo limestone;* [2] *(Pliocene) Caloosahatchee marl;* [3] *(Miocene) Tamiami limestone.*

Tamiami formation and the study of greatly expanded fossil collections (chiefly from the outcrop area of the Tamiami formation) have made it necessary to revise the correlations of formations in this area. It is now believed that:

1. The Key Largo limestone (Pleistocene reef rock that crops out at the surface in the upper Florida Keys) extends considerably farther west, and deeper, than previously thought (1, 9).

2. The Fort Thompson formation, a Pleistocene unit consisting of alternating marine and fresh water limestones, thickens greatly to the south from the outcrop area and here makes up the greater bulk of the section previously assigned to the Tamiami formation (Fig. 3).

3. The Caloosahatchee marl exists only as a thin wedge or as discontinuous erosion remnants preserved in depressions in the underlying, older materials.

4. The Tamiami formation is of upper Miocene age and, as here indicated, includes all deposits of that age in southern Florida. As thus defined, it includes the Tamiami limestone and Buckingham limestone of Mansfield (12) and the upper part of the Hawthorn formation of Parker and Cooke (1). Agreement exists upon this correlation, first suggested by MacNeil,* which is based on fossil evidence that will be presented in a subsequent article.

The uppermost limestone unit of the Biscayne aquifer is the Miami oolite. This is the surficial rock that is commonly called coral rock. It is not actually coral for there is less than 0.1 per cent of true reef materials in the oolite—coral rock is found in surface outcrops in Florida only in the Keys. Excellent examples of the highly permeable coral reef rocks (the Key Largo limestone) are seen in the shallow road cuts along the Key West highway soon after entering Key Largo.

The Miami oolite is a thin wedge (Fig. 3) having a 40-ft. maximum thickness under the Atlantic Coastal Ridge but averaging from 20 to 30 ft. Throughout most of its area of outcrop, the rock is riddled with solution holes that have a remarkable vertical development and a correspondingly high permeability. Even the heaviest rains vanish into the rock soon after falling.

A very minor part of the Biscayne aquifer is the Pamlico sand, the veneer of white quartz sand that generally mantles the coastal ridge as far south as Coral Gables. In some places—especially between North Miami and Fort Lauderdale—old, deeply incised drainage channels are now filled with this permeable sand. Some of these sand-filled channels are as much as 100 ft. deep and hundreds of yards wide. In such places the Pamlico sand is highly important for the development of wells, which are ordinarily finished with a sand point.

The general geologic features of the Biscayne aquifer are shown in Fig. 4, which indicates that the aquifer is approximately 100–125 ft. thick in the Miami area. On its seaward side, the aquifer contains no barriers that would shut out sea water. The aquifer is indeed every bit as open and permeable in the Biscayne Bay area as it is inland, perhaps more so.

Hydrologic Characteristics

The Biscayne aquifer is a hydrologic unit, but owing to its geology, the hydrologic characteristics are not everywhere uniform. Mainly, however, it is one of the most highly permeable aquifers ever investigated by the U.S. Geological Survey, and is comparable with coarse, clean, well sorted gravel in ability to transmit water.

* Private communication from F. Stearns MacNeil, Geologist, U. S. Geol. Survey, Washington, D.C.

The coefficient of permeability is one of the most common means of expressing the capability of earth materials to transmit water. Meinzer (13) defines this coefficient as the rate of flow of water at 60°F., in gallons per day, through a cross section of 1 sq.ft. under a hydraulic gradient of 100 per cent. A related coefficient, called the field coefficient of permeability, is commonly used in the field for convenience. It is defined (13) as: "the rate of flow of water, in gallons a day, under prevailing conditions, through each foot of thickness of a given aquifer in a width of 1 mile for each foot per mile of hydraulic gradient." Theis (14) introduced the term "coefficient of transmissibility," the field coefficient of permeability multiplied by the saturated thickness, in feet, of the aquifer.

Ordinary earth materials that have been tested in the hydrologic laboratory of the U.S. Geological Survey were found to have permeability coefficients ranging from approximately 0.0002 to approximately 90,000, although materials of most aquifers have values ranging between 10 and 5,000. More than a dozen field quantitative tests made by the U.S. Geological Survey in different parts of the Biscayne aquifer indicate that average permeability coefficients range from approximately 50,000 to 70,000, and in one test (TW 1, Southwest well field area) the indicated coefficient was somewhat higher than 180,000. No great reliance is placed upon the last value, however, for turbulent flow in the solution channels of the limestone made use of the standard formula partly invalid.

Stating the water-bearing capacity of this aquifer in terms of common experience, an average well of 6-in. diameter, having casing that is seated in rock at 40–95 ft. below land surface and having an uncased open hole extending a few feet below the end of casing, will yield at least 1,000 gpm. with less than 2 ft. of drawdown. Test wells of 18-in. diameter in the new Southwest well field area were pumped at rates of 5 mgd. each, and drawdowns in these wells ranged from about 0.8 to 3.6 ft. Using the water table gradient obtained during one of the pumping tests, it was reckoned by Warren (3) that the ground water velocity toward the pumped wells at a distance of about 100 ft. was about 0.12 fpm., or approximately 180 ft. per day.

Specific Yield

Meinzer (15) defined specific yield as the amount of water free to drain out of a material by gravity under natural conditions, expressed as the fraction of the total volume of rock dewatered. The specific yield or effective porosity of the Biscayne aquifer ranges from approximately 0.10 to 0.35 and averages approximately 0.20. If every bit of precipitation that fell during a storm were to be added directly to the ground water body, each inch would cause an average water-table rise of 5 in. Seldom are conditions such that so large a part of the rainfall finds its way into the aquifer, although measurements made by automatic recording gages on observation wells in the Miami area indicate that this ideal utilization of rainfall has been approached. Very little overland runoff occurs in this area if the water table is below the land surface.

Natural Recharge and Discharge

Recharge to the Biscayne aquifer is chiefly from local rainfall, which in the rainy season is so concentrated that ground water mounds often build up under the Atlantic coastal ridge to

heights considerably above the water level in the Everglades to the west. During such times, large quantities of ground water discharge westward into the Everglades, as well as eastward into Biscayne Bay.

Studies completed in 1946 by Warren (3) indicate that, of the nearly 60 in. (average through 1945) of average annual rainfall in southeastern Florida, 38 in. reaches the water table directly and within a short time after falling. The remaining 22 in. is lost by evapotranspiration and surface runoff before it can reach the water table.

The canals of this area are generally not effective sources of fresh water recharge to the Biscayne aquifer; rather, they are highly effective in draining away ground water. A mile of drainage canal is ordinarily somewhat more than twice as effective as a mile of shore line along Biscayne Bay in discharging ground water. But in areas in which dams are placed in canals or in areas of localized water-table lowering adjacent to canals (as where a cone of depression around pumped wells intersects a canal), the canals feed water to the aquifer. The added water may then amount to a very considerable part of the total pumped. Approximately 50 per cent of the water pumped from the Hialeah-Miami Springs well field of the city of Miami appears to come from the Miami canal on the north and northeast and from the borrow pit of the Florida East Coast Railway on the west.

Discharge from the Biscayne aquifer (the land surface is considered to be the top of the aquifer) takes place chiefly through the following means: [1] ground water flow, both into drainage canals and thence into Biscayne Bay and directly into the Bay, [2] evapotranspirative losses to the atmosphere, and [3] pumping.

Of the 60-in. average annual rainfall, the first means accounts for approximately 20 in. and the second for approximately 38 in. (of which 22 in. is lost before the water can reach the water table, and 16 in. is lost from the water table). The third loss, pumpage, is very difficult to account for in Dade County because most users do not keep satisfactory records. In the last year that an exhaustive study of this loss was made (1945), the pumpage amounted to about 58.4 mgd. or 21,300 mil.gal. per year. Throughout the approximately 600 square miles of that part of Dade County in which pumping mainly occurs, this is approximately 2 in. of rainfall per year.

In areas of heavy pumping such as the proposed Southwest well field that will pump approximately 50 mgd., the resultant lowering of the water table in the area of the cone of depression will salvage an estimated 8.6 in. of water that otherwise will be lost as a part of the total evapotranspirative loss. This is actually an increment to the usable storage of the aquifer for it provides that much more available water for human use.

Development of Wells

Most wells in the Miami area are drilled, have a casing seated in rock, and have a few feet of open hole below the casing shoe. Many are simply pipes that have been driven into the rock or sand a few feet below the water table. Most industrial supply wells are 50–60 ft. deep, and the deepest go down 100 ft. Typical of the large capacity wells are those of the Miami Springs-Hialeah well field which range in depth from 60 to 95 ft. and supply as much as 6 mgd. each.

Well water is so easily obtained from the Biscayne aquifer that supplies for fire fighting are commonly obtained from "fire wells." These wells are usually of 6-in. diameter and supply at least 1,000 gpm. with negligible drawdown. Another common type of well is the drainage or dry well which differs from other wells only in its use. Throughout most of this area, such wells are used for disposing of surplus rain water that gathers in the streets or even on the tops of downtown buildings. Ending in solution-riddled limestone, such wells seldom clog, and if they do, they can be cleaned out readily by bailing and surging or by being blown out with compressed air.

Laundry and other industrial wastes are commonly disposed of in drainage wells when a permit is granted by the state board of health. This practice is not encouraged by the board, but is permitted in certain areas, although only until a sanitary sewer system is provided. Those areas in which the ground water is already so highly saline as to be unfit for human consumption, and into which the waste liquid can be injected directly through the disposal wells may be presently used for this purpose. The area that can be so used is generally limited to a part of the stippled region of the 1950 map in Fig. 5.

Safe or Perennial Yield

Safe yield is a term that is commonly used in discussion of the development and use of aquifers. It is often used, however, without thought of the precise meaning of the term. Safe yield once had a widely understood meaning—the quantity of water that can be taken from an aquifer without exceeding the rate of replenishment or causing impairment of the quality of water in the aquifer. No aspect of ethical or justifiable withdrawal was involved in this concept, nor were economics always considered. Meinzer (15, p. 55) defined safe yield of a given aquifer as "the rate at which water can be withdrawn for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible." This economic aspect is, however, difficult to appraise. It seems far better to confine the definition to a concept that includes only the quantity of potable water perennially available in an aquifer without quality impairment, and it might better be called "perennial yield." The author has adopted this latter term and concept.

Salt Water Encroachment

The problem of salt water encroachment in the Miami area has received wide note in the public and scientific press. Rather complete accounts (10, 16) appear in technical journals.

Salt water encroachment is usually the chief limitation to the use of water from the Biscayne aquifer. Unlike many other areas in which this encroachment has been caused by pumping, however, in the Miami area it is caused by the drainage canals.

The canals have effectively induced encroachment by two chief means:

1. They have served to drain off fresh water stored in the aquifer in the coastal zone.

2. They have acted during certain dry periods as inland extensions of the sea, carrying salty water inland for several miles and allowing it to leak out to contaminate the aquifer all along their course.

Lowering the water table nearly to sea level under the coastal ridge has caused a loss in head in some places of

approximately 5 ft. compared with the original head before drainage began. Not only is this a large actual loss of fresh water in storage, but it is the factor that led to the inland movement of a salt water wedge from Biscayne Bay, operating in accordance with the Ghyben-Herzberg principle.

The five maps in Fig. 5 show the general pattern of encroachment into the Biscayne aquifer in the Miami area for a period of 47 years. They show that the major spread of the salt water wedge occurred between 1943 and 1946. During that time, a lengthy drought occurred, and in 1945, water levels fell to all time lows in this area. Parker (16) reckoned, on the basis of studies in the Silver Bluff area, that the rate of encroachment until 1943 had been approximately 235 ft. per year. In a 27-month period that overlapped 1943–44 the front of the salt wedge advanced 2,000 ft., or at a rate of approximately 890 ft. a year.

To arrest this threat to the local water supply, Dade County and city of Miami officials cooperated in the emplacement of low level removable dams in tidal canals. Local opposition prevented the placement of dams in the Miami Canal east of the N.W. 36th Street bridge site, and in the Coral Gables and Tamiami Canals east of Red Road. The change of encroachment pattern shown in Fig. 5, by comparing the map for 1946 with that for 1950, bears mute witness to the results of this difference. On the Biscayne, Little River and Miami Canals, actual seaward retreat of the inland ends of the tongues of salt water has occurred. In each of these areas, the dams prevented additional inland intrusion of sea water during the dry seasons after their installation and have also raised the fresh water head in the aquifer somewhat.

By contrast, the contamination patterns along the Tamiami and Coral Gables Canals should be noted. The former canal empties into the Miami Canal downstream from the 36th Street dam site and is therefore vulnerable to salt water incursions up the unprotected channel. Both the Coral Gables and Tamiami Canals were dammed at Red Road, but low stage and low flow enabled sea water to penetrate as far as the dams. The continued spread of salt water contamination in these two areas is therefore directly attributable to the lack of downstream salt water control dams.

In the intercanal areas parallel to the shore line of Biscayne Bay, the wedge of salt water has generally maintained the 1946 position. This condition speaks well for the water control program which has not only excluded the sea water above the dams but has also caused higher average water levels in the affected areas. This action, together with increased rainfall since 1947, has slowed the 890-ft.-per-year encroachment rate to practically zero. Only in the area of the Coral Gables Canal has the intercanal contamination migrated inland. This movement is probably caused by the increased opportunity for salt water to gain access from the bay through newly dredged canals in that area.

Estimation of Effect

Estimation of the effect of salt water encroachment in the Biscayne aquifer at Miami is complicated but not too difficult. The aquifer is floored at an average depth of approximately 100 ft. by a thick sequence of relatively impermeable materials (the Floridan aquiclude). The aquiclude prevents both

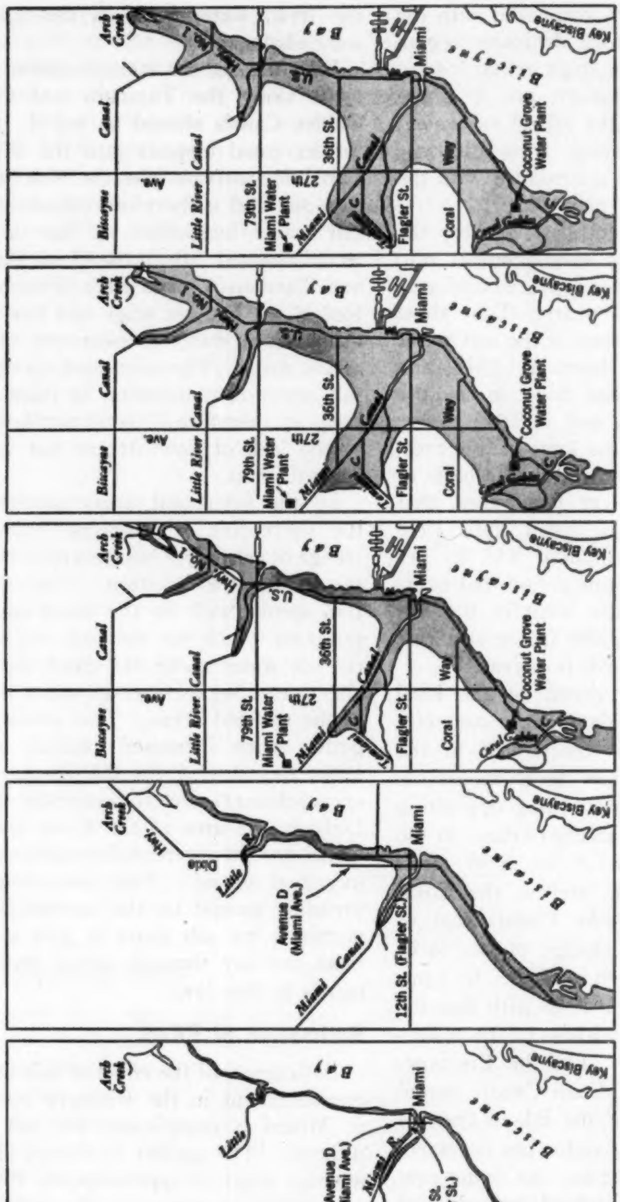

Fig. 5. Salt Water Encroachment

Progressive salt water encroachment in Miami area from 1904 through 1950. The encroachment is represented by shaded portions of the maps.

the presence of salt water immediately beneath the aquifer and the presence of a deep lens of fresh water floating upon salt water in the aquifer as would otherwise occur if all the materials were permeable to very great depths. The Ghyben-Herzberg ratio is nevertheless believed to operate, but only above the relatively impermeable floor of the aquifer and through the interface between the fresh water of the aquifer and salt water of Biscayne Bay. Thus, given an aquifer sealed at the base and only 100 ft. deep, and assuming the sea water to have a specific gravity of 1.025, 2.5 ft. (100/40) of fresh water above sea level is all that is required to hold salt water out completely.

Quite a different situation exists on the Florida Keys in which a small lens of fresh water, if present, rests entirely on and in equilibrium with sea water under each key. In a paper soon to be published, Wentworth (17) discusses the safe yield of such insular areas very lucidly. He states in part:

> It appears that in a large Ghyben-Herzberg system where the total storage in the lens above and below sea level is of the order of twenty times the annual rainfall on the same area and perhaps 50–100 times the annual ground water circulation, the direct contemporary measurement of safe yield or increment yield is impossible. On the other hand, when the consideration of various lags and cycles takes in a period of several decades there is likely also to be involved a number of social and technical trends of equal duration which are also not susceptible of categorical evaluation. The problem thus becomes one of progressive approximations in the light of such hydraulic and social facts as can be ascertained, and the quantity of water is better spoken of as a justifiable draft rather than a safe yield.
>
> With respect to a small, isolated island, where the lens of fresh and brackish water may be only a few feet in thickness, the term safe is more suitable, since the usable fresh water in the Ghyben-Herzberg lens may here be no more than a few weeks or months of ground water circulation. In fact, it is often the case that owing to the precarious conditions of fresh water circulation at sea level, the Ghyben-Herzberg lens may furnish no water of low salinity or may be subject to immediate and rather rapid increase in salinity when a draft of useful rate is applied. Here the determination of how much water can be drawn under given salinity limits and how the amount may be moderately increased by suitable design of a well or tunnel becomes at once a practical problem. The greatest caution must be employed in interpreting results of measurement of water levels, qualities and quantities, since the principle still holds that any draft from such a balanced natural water body must at first consist both of yield from some combination of recent rainfall and of water derived in reduction of storage. Only a long period of steady draft under new conditions will indicate what steady quantities and qualities can be expected, and it can be extremely costly if early increases of quantity without adequate analyses of quality are accepted too optimistically.

Pumping and Perennial Yield

It has been claimed by uninformed or misguided people that pumping of the Miami well field was causing the salt water encroachment in the aquifer. This contention completely disproved the maps in Fig. 5. Although an average of 50 mgd. is now being pumped from the Miami Springs-Hialeah well field, as compared with an average of approximately 30 mgd. in 1943–46, the tongue of salt water beyond the 36th Street dam site of the Miami Canal has noticeably retreated seaward. If the pumping of the well field had been the

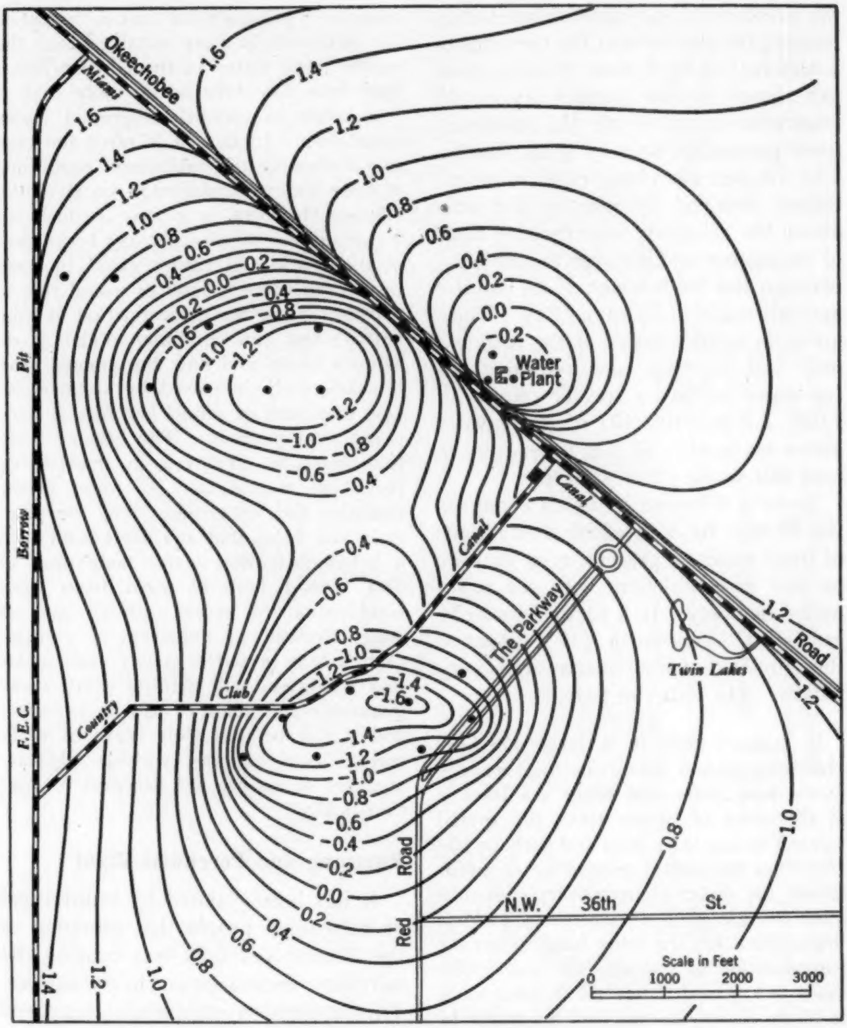

Fig. 6. Miami Well Field

Map of Miami well field for June 27, 1950, indicates cones of depression resulting from pumping at rate of 60 mgd. Black dots represent supply wells. Water table contours are at 0.2-ft. intervals referred to mean sea level.

cause of its presence in 1943 or 1946, this tongue would now be farther advanced, if not actually within the field. Since no large pumping plants are located inland at the ends of each of the other tongues of the encroaching salt water, these tongues are obviously directly related to and also caused by the canals along the courses of which they lie.

Pumping a well in this area at a rate of several thousand gallons a minute scarcely makes a dimple in the water table. To make accurate and usable maps of the cone of depression around areas of large pumping, such as the Miami Springs-Hialeah well field, the U.S. Geological Survey has resorted to the preparation of maps having contour intervals of 0.2 ft. A map of this sort is shown in Fig. 6.

Little pumping indeed is done in the Miami area when compared with the runoff through the drainage canals or with the total loss caused by evapotranspiration. Given an area reasonably far removed from salt water in the aquifer, large additional volumes of water, several times that now used, could be pumped and not affect the perennial yield of the aquifer adversely.

Storage and Perennial Yield

The canal systems of this area have lowered the average water level under the Atlantic coastal ridge in some places approximately 5 ft. Under this lowered head, which upset the previously existing equilibrium between fresh and salt water in the coastal area, the salt water began moving inland to reestablish a balance. Given an aquifer extending 100 ft. below sea level, the average water table elevation that will keep salt water out is 2.5 ft. At some future time, then, an equilibrium will again be established and the salt water wedge will come to rest where the average annual contour on the water table is 2.5 ft. above average sea level (not mean sea level datum, which is about ± 0.5 ft. below average bay level).

The only effective storage that can be assumed perennially for large ground water supplies lies to the west of this 2.5-ft. contour (Fig. 7). The location of this 2.5-ft. average annual contour on the water table was plotted. West of this contour in Dade County lies a great area of aquifer that contains a usable ground water supply greatly exceeding the amount of water available in Lake Okeechobee. It is Miami's great underground storage reservoir and is one of the city's greatest natural assets.

As time goes on, and this area becomes more thickly populated, there will be much greater demands for water. Haphazard and poorly planned ground water developments or drainage programs could ruin parts or all of the aquifer. Great care must be exercised to prevent this occurrence. A careful, day-by-day and year-by-year accounting of storage, salt water encroachment, recharge and discharge will therefore be important. That accounting can be made by state and federal geological surveys, but the controls, planning and action needed to preserve and use the aquifer must be instituted by the local water works personnel and legislative agencies.

Summary and Conclusions

The Miami area cannot draw on deep artesian supplies, 800–1,000 feet below the land surface, because the water in the Floridan aquifer of this area is too saline and corrosive for most purposes. No water is available in the Floridan aquiclude, either, for that thick sequence of clay, silt, and marl which caps the Floridan aquifer and forms a basement under the permeable rocks of this area is relatively impermeable. Miami does, however, have an excellent source of ground water available for ready and easy development in the Biscayne aquifer, which receives an effective recharge of approximately 38 in. of rainfall from the total annual precipitation of almost 60 in. This underground reservoir is approximately 100 ft. in average depth

under the Atlantic coastal ridge and is one of the most permeable aquifers ever investigated by the U.S. Geological Survey. The field coefficient of permeability averages approximately 50,000–70,000 but may range to values more than twice as great. The eastern side of the aquifer is open to the ocean, and during the course of 47 years since drainage operations in the Everglades began, salt water encroachment has taken place by two means:

1. By inland movement of a wedge of salt water all along the coastal side of the aquifer

2. Up tidal canals and thence out into the aquifer by leakage through the sides and bottoms of the canals.

During 1943–44 the rate of movement of the salt-water wedge for the Silver Bluff intercanal area was calculated to be at a rate of 890 ft. per year. Since then, Dade County has embarked upon a water control program that is very effective in the coastal ends of the Biscayne and Little River Canals, and in the Miami Canal above the 36th Street bridge. In those areas, since the controls became operative, there has been a retreat of the salt water wedge. In areas along the uncontrolled Tamiami and Coral Gables Canals (uncontrolled in their lower reaches) further encroachment of the salt water wedge has occurred and is still going on. In the Silver Bluff area, midway between the Miami and Coral Gables Canals, the wedge of encroaching salt water has held its 1946 position.

Salt water encroachment in the Miami area, as in all coastal zones where fresh ground water is in contact with sea water, appears to take place in accordance with the Ghyben-Herzberg principle. The Biscayne aquifer having a relatively impermeable floor at approximately 100 ft. below sea level, however, is not subject to direct vertical contamination from salt water. Salt water deep in the aquifer must, instead, move above the relatively impermeable floor, and in the face of a fresh water head of 2.5 ft. above sea level, could not move in at all. This situation makes computation

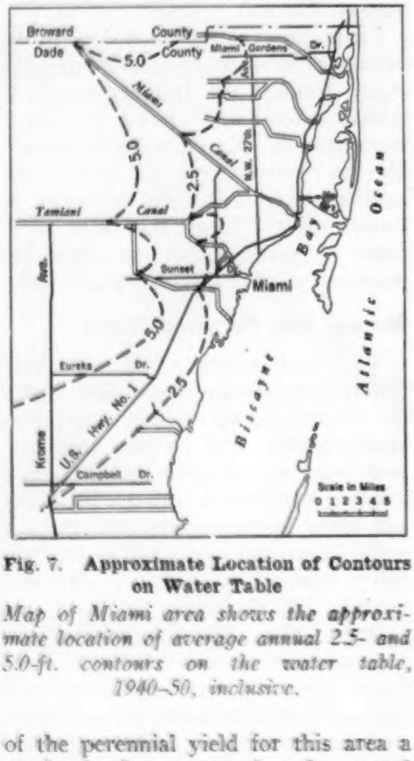

Fig. 7. Approximate Location of Contours on Water Table

Map of Miami area shows the approximate location of average annual 2.5- and 5.0-ft. contours on the water table, 1940–50, inclusive.

of the perennial yield for this area a much simpler matter than in coastal areas underlain to considerably greater depths by freely permeable materials. In such other places, in accordance with the 40:1 Ghyben-Herzberg ratio, the initial yields from bottom storage in the early phases of overheavy development of the aquifer will be much larger than will be supplied in later phases,

when storage shrinks at an increasing rate. Very large ground water supplies for future exploitation still exist in the Biscayne aquifer, and are perennially safe in that part of the aquifer lying to the west of a 2.5-ft. average annual contour on the water table. For its permanent protection, however, storage in the aquifer must be measured and critically evaluated regularly, salt water encroachment must be strictly controlled and adequate future development must be arranged locally.

Acknowledgments

The information presented in this paper is the outgrowth of geologic and ground-water studies that began in southeastern Florida in 1939, in cooperation between the U.S. Geological Survey and Dade County, the cities of Miami, Miami Beach, and Coral Gables and the Florida Geological Survey. Grateful acknowledgment is made to the officials of each of these organizations for their continued interest and help.

Appreciation and gratitude is expressed also for the assistance of the following U.S. Geological Survey personnel in the preparation of this report to:

Nevin D. Hoy, Dist. Geologist, and Melvin D. Schroeder, Geologist, of the U.S. Geological Survey district office in Miami, Fla., for assembling cores from test wells in the Miami area and other data, and for critical review of the manuscript; Ross A. Ellwood, Scientific Illustrator, Miami district office, who prepared the illustrations; John H. Christensen, Geologist, U.S. Geological Survey, Washington, D.C., for aid in assembling part of the data for this report and for laying out the fence diagram (Fig. 4); the author's other colleagues in the Washington office who have offered many valuable suggestions for the improvement of the paper, especially F. Stearns MacNeil, C. Wythe Cooke and Julia A. Gardner, Geologists, for paleontologic determinations and assistance in making the stratigraphic correlations.

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Discussion

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Of the various factors governing safe yield of ground water supplies cited in these papers, it is obvious that some are directly applicable to water supply problems in the Miami area. A few of the problems which must be considered by the city of Miami in the development and maintenance of its municipal water supply system should therefore be mentioned.

One of the major difficulties in planning a new well field is to select an area that is a safe distance away from any possible salt water contamination from the ocean or bay through the water-bearing formations. For this purpose, the location must permit the perennial maintenance of a head of fresh water between the well field and the ocean or bay sufficient to prevent the salt water from encroaching on the well field. It is also necessary to determine what effect the estimated pumpage from the new well field will have on water levels in the area, especially if the estimated pumpage will cause an appreciable lowering of ground water levels over a wide area.

Other sources of salt water contamination, and perhaps more serious ones in the Miami area, are the many tidal canals which exist in this area. To this problem, some might suggest the simple solution of selecting the new well field a sufficient distance from a tidal canal. At the time of selection, the well may be at a safe distance from any existing tidal canals, but a new canal may be constructed or an existing one enlarged at a subsequent time, thus causing a decided threat of salt water contamination to the new well field. If existing and potential municipal ground water supplies are to be protected, it will be necessary to construct and maintain proper control features in the tidal canals. By proper controls, an inland movement of salt water in the canals can be prevented, and, at the same time, ground water levels can be held at the highest feasible stage.

Well Spacing

In the actual development of a new well field, an important factor to be borne in mind is well spacing because:

1. The more closely the wells are spaced, the less land is required.

2. Ten times as much pipe is needed for wells spaced 1,000 ft. apart as for those 100 ft. apart.

3. Well spacing will largely determine the shape and size of the cone of depression which pumping will develop.

A large proportion of the total annual rainfall in the Miami area occurs from June through October, a period that generally coincides with the hurricane season. This combination of circumstances, taken together or separately, quite frequently causes extremely high water levels which must be considered in the design of a new well field if water service is to be maintained during these periods. Access roads and pump settings must therefore be constructed at a safe elevation. Figuratively speaking, it may be said that this condition provides too much water, but there is also a period of too little water. This period is generally from January through March, when scanty rainfall occasions the use of tremendous quantities of water for lawn sprinkling. This added consumption, together with the heavy influx of tourists, causes peak water consumption during the period of low ground water levels. Several municipalities in southern Florida have from time to time restricted or prohibited sprinkling to reduce the strain on plant capacities.

All the above problems, and many more, were considered in developing Miami's Southwest Well Field and in operating the Miami Springs Well Field.

If the Miami area continues its rapid growth—and it probably will—the water supply systems will have to keep pace. Steps will have to be taken to protect existing ground water supplies and develop additional water supplies, and these measures will have to be based on sound hydrologic data.

Correction

In the paper "Water Fluoridation—A Sound Public Health Practice" by Charles R. Cox and David B. Ast, which appeared in the August 1951 Journal, Fig. 1 and 2 were mislabelled. In Fig. 1 on p. 644, the bars representing the years covered in the Kingston study should have been marked "1945–46, 1947, 1948, 1949" instead of "1945–46, 1947–48, 1948–49, 1949–50." The vertical axis of the graph in Fig. 2 on p. 646 should have been designated "DMF Permanent Teeth per Child" instead of "DMF Rate per Child."

Amendments to A.W.W.A. By-Laws

The following amendments to Article I (Membership) and Article III (Fees and Dues) of the Association's By-Laws were approved by letter ballot of the membership as of September 4, 1951, and become effective as of that date.

Article I has been expanded to include a new section that reads:

Section 3. A Life Member shall be any Active member in good standing who has paid dues continuously for 30 years. A Life Member shall not be required to pay any dues for the support of the Association.

The present Sections 3–8 will be renumbered 4–9.

Article III has been amended by the deletion of the present text of Sections 1–5. The new version of Section 1 reads:

Section 1. Each Active, Corporate, Associate and Junior Member and Affiliate shall pay annual dues in the amount currently in effect for each class of membership as directed by the Board of Directors.

As the Association has not required an initiation fee from a member in good standing of an Affiliate Association or Society who has been elected to active membership, the provision for that charge has been deleted from Section 1.

Section 2 will now read:

Section 2. Honorary Members and Life Members shall pay no annual dues.

Section 6 to be renumbered Section 3.
Section 7 to be renumbered Section 4.
Section 8 to be renumbered Section 5, and revised to read:

Section 5. Municipal Service Subscribers shall pay for the publications, bulletins and services as described, at the same annual rate as the dues charged Corporate Members.

Section 6 will read:

Section 6. Changes in the amount of annual dues required of Active, Corporate, Associate, Junior and Affiliate Members may be made by the Board in the manner prescribed in Article X for amendment of these By-Laws, provided that such action is completed not less than 90 days prior to the end of the calendar year preceding the effective date of such change.

The Organic Nitrogen Problem

By D. B. Williams

A contribution to the Journal by D. B. Williams, in Charge of Purif., Public Utilities, Water Works Lab., Brantford, Ont.

THIS discussion calls attention to the presence of organic nitrogenous substances in raw waters as a distinct problem in water purification, briefly indicates the general knowledge of the subject and assesses various treatment procedures.

The presence and amount of organically combined nitrogen in water are determined by the two analytical procedures for albuminoid ammonia and total organic nitrogen (1, 2). Some workers (3) consider that albuminoid NH_3 represents amino acids and peptones, whereas total organic nitrogen represents not only amino acids and peptones but also proteins, which are very complex molecules composed of one or more amino acids. For brevity the term "protein" will be used in a general sense to cover all forms of organic nitrogen unless otherwise stated.

Scope of Protein Problem

Recognition of the protein problem is not new. Houston (4) and Hoover * in the early nineteen hundreds showed that partial removal of protein could be accomplished by treatment with excess lime. Thresh, Beale and Suckling (2) reported successful application of Houston's work.

Domestic sewage, either untreated or subjected to various degrees of treatment and industrial wastes, particularly from the food industries, are large contributors of proteins to surface waters. Wool scouring wastes are outstanding protein sources (5). The algae are large contributors, and some of the amino acids involved have been estimated and identified (6). Fogg (7) showed that blue-green algae can elaborate protein, requiring in addition to water only carbon dioxide, atmospheric nitrogen and mineral salts.

The water treatment problems caused by protein contamination are increasing. The wide application of free residual chlorination and the maintenance of highly reactive residuals composed largely of free available chlorine have also augmented the need for more intensive study.

Todd (8) suggested that, where protein contamination is especially severe, sewage treatment procedures be applied to raw water before using the more conventional water purification practices are used. The utility of this suggestion has already been confirmed in the studies made in England by Pugh (9), who successfully treated water in a trickling filter, for purposes other than protein removal, before applying coagulation and chlorination.

It remains to be demonstrated whether or not the presence of proteins

* Charles P. Hoover, Supt., Div. of Water, Columbus, Ohio. Correspondence with Houston.

and their chloro derivatives in drinking water constitutes a pathological hazard. It has not been established that proteins as such are taste- and odor-producing bodies, although the association of high protein content and high taste and odor incidence is common. In taste- and odor-free water that requires little chlorination to produce adequate safety, the protein content would probably not be significant or even noticeable.

Proteins constitute an acute problem when associated with intense tastes and odors and very high concentrations of bacteria, because these conditions necessitate the use of free residual chlorination.

The basis of the problem is the slow reaction between free chlorine and protein. Griffin (10) has shown that the reaction between free NH_3 and free chlorine is of relatively short duration and may be completed by providing a reasonable detention time. With protein, the reaction involves a "chlorine demand in time" (11). To complete the reactions between protein and chlorine, chlorine residuals far above the break point (superchlorination) and several days' detention time may be required. Todd's (12) recent suggestion that water heavily dosed with chlorine and chlorine dioxide be stored for approximately 30 days before use evolved from this requirement. The ordinary water purification plant neither has nor can afford to acquire capacity to accomplish this storage.

Feben and Taras (13, 14) have provided a mathematical formula for determining the time of reaction between proteins and chlorine, and show that any residual of free chlorine may be maintained in water leaving the plant with uniform pumpage and a constant and fairly low protein content. Without detracting from the importance of this work, Faber and Hedgepeth (14) point out the impossibility of such control when protein pollution is heavy and variable—as at Brantford.

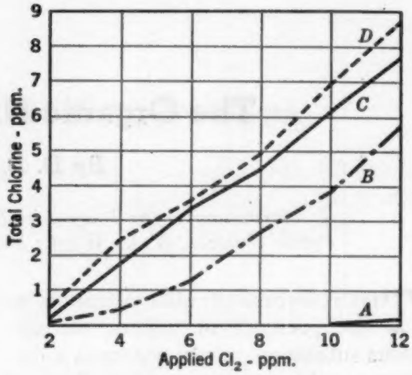

Fig. 1. Effect of Protein Content on Free Residual Chlorine Stability

Free NH_3 was absent. Strong protein concentrations resulted in unstable free chlorine residuals, whereas weak concentrations or absence of protein resulted in very stable free chlorine residuals. Curve A *represents untreated raw water with 1.040 ppm. albuminoid NH_3 before adding Cl_2; Curve* B, *water treated by simple filtration through glass wool with 0.184 ppm. albuminoid NH_3 before chlorine addition; Curve* C, *coagulated and filtered water with pH restored to 8 and 4 grains of alum added having 0.110 ppm. albuminoid NH_3 before chlorination; Curve* D, *coagulated, filtered, aerated water having the original pH of 8, excess lime, 2 grains alum and excess CO_2 with 0.080 ppm. albuminoid NH_3 before chlorination. The contact time was 24 hours. Total chlorine content was determined by amperometric titration and was found to be 95 per cent free chlorine.*

Summary of Problem

The protein problem under conditions of free residual chlorination is:

1. Chlorination, considerably above the break point, is required if tastes and odors are to be oxidized (11), and this treatment adds materially to costs.

2. Greatly extended storage under free residual chlorination conditions is necessary (12) if all reactions are to be sufficiently complete to maintain a stable, free chlorine residual in the finished water.

3. Chlorine that could be more usefully employed in the destruction of bacteria and oxidation of taste and odor substances is consumed in reactions with proteins.

4. If reaction time with free chlorine is limited, higher chlorine dosages followed by part or total dechlorination are required—all adding to cost.

5. Even in alkaline water, reactions between free chlorine and proteins produce nitrogen trichloride (11, 15), which must be removed to keep complaints at a minimum.

6. When all NCl_3 is removed at the treatment plant, additional and even greater amounts of NCl_3 will be generated throughout the distribution system whenever protein and free chlorine coexist. This condition led to the use at Brantford (16) and elsewhere of complete dechlorination followed by chloramination. In the absence of protein, only partial dechlorination to a free chlorine residual would have been required. The presence of protein necessitated the maintenance of a final combined residual rather than the free chlorine residual desired.

7. The presence of protein in finished water is probably largely responsible for the great variability in reports of the relative stability of residuals of free chlorine and chloramine in distribution systems. For all practical purposes, the chloramines are unaffected by the presence or absence of protein in the water and provide a stable chlorine residual. In water having a strong protein content, free available chlorine residuals are unstable. If protein is absent or of weak concentration, free available chlorine residuals will be very stable (Fig. 1).

In chlorination below the break point (combined residual chlorination), no appreciable reaction occurs between chlorine and protein. It may well be asked why chlorination below this point is not utilized to sidestep the protein problem. The quicker and greater bactericidal effect of free residual chlorination in the treatment of heavily polluted waters is an immediate and important reason. Other reasons are offered by the many discussions of the proved advantages of free residual chlorination. Progress toward sterility and other benefits derived from free residual chlorination is thus technically and economically hampered by proteins.

Present Removal Procedures

The complete elimination of all protein from rivers, particularly in thickly populated areas, is most unlikely. Even if all protein contributed by man could be eliminated, the problem of algae-produced protein would remain.

Reduction in the protein content of natural waters can be accomplished by conservation of watersheds, more adequate treatment of sewages and wastes and the general application of antipollution measures. Any action that will reduce support of algae growths in streams is desirable.

Proteins can be at least partially removed at the water works before application of free residual chlorination. The degree of removal attained will depend on the amount of protein present, the procedure selected for removal, design features of the treatment plant

(coagulation, sedimentation and filtration) and whether the protein substances are present as a visible suspension or a colloidal solution. Other factors such as the chemical qualities of the raw water which relate to coagulation may also influence protein removal.

The following summary which indicates and assesses the various current procedures available is based on the experimental treatment of Grand River water at Brantford.

Sedimentation and Filtration

Ordinary sedimentation and simple filtration without the application of coagulants will remove protein existing in the water in visible suspension, although they will not affect protein existing in colloidal solution. The addition of chemical coagulation to these processes assists mechanically in the removal of suspended protein. Removal of suspended protein is therefore not a serious problem.

Chemical Coagulation

Protein in colloidal solution is not so easily removed from water, and this type of organic matter constitutes the crux of the protein problem. Chemical coagulation, using well known coagulants, currently appears to be the most practical solution.

Results obtained with the various coagulants are as follows:

1. *Excess lime.* Excess lime treatment removes a greater proportion of protein from water than any other single treatment tried. Protein removals of 55 to 75 per cent have been found, and removals are generally more than of 60 per cent. Use of alum as an aid to excess lime produces a slight improvement in protein removal plus the added advantage of larger, faster-settling floc. Results obtained with lime dosages below the excess lime level (either as the main coagulant or as an aid to other coagulants) have not been promising on Grand River water, although these results may not apply to other raw waters.

2. *Aluminum sulfate and ferric salts.* Aluminum sulfate, ferric sulfate and ferric chloride coagulants follow excess lime in ability to remove protein from water. Results occasionally favor one over the others, but the slight differences have been within experimental error. For all practical purposes, they appear to be equal in accomplishing protein removal. Other factors may determine the most suitable coagulant. Protein removals of 20 to 60 per cent have been found, a 30 per cent removal being normal.

3. *Excess coagulants.* Use of aluminum sulfate, ferric sulfate and ferric chloride is assumed to be on the basis of adding sufficient coagulant to give a floc having satisfactory settling and filtering qualities. Coagulation judged from this viewpoint does not indicate that maximum protein removal has been attained. Doubling or tripling the coagulant dosage that is required to give a floc that appears satisfactory will accomplish further protein removals. Removals of 35 to 65 per cent have been found, 45 per cent being normal. Coagulation should not be judged merely by floc appearance, however, because residual organic nitrogen determinations are important.

The general statement that all plants should, or would even find it necessary to, double or triple their normal coagulant dosage cannot be made. By improved and more adequate coagulation followed by filtration prior to the application of free residual chlorination, many plants can show chlorine

savings, general reduction of the protein-chlorine problem and a possible alternative for the costly installation of greatly increased retention capacity.

If protein is a problem, efficient coagulation and filtration of the water should precede free residual chlorination. The application of chlorine before filtration may still be desirable, and if the prefilter chlorine dosage is maintained below the break point, no reaction with protein will occur.

4. *Activated carbon and activated silica.* No indication that activated carbon would remove protein from solution has been noticed at Brantford, although such has been indicated elsewhere. These conflicting results may stem from differences in the conditions of pH and temperature and in the type and concentration of organic nitrogen pollution present.

Activated silica as a coagulant aid has not influenced colloidal protein removal. It does produce tough, large floc particles, thus aiding the purely physical aspects of settling and filtration. Organic matter in suspension (particularly some of the live Cyanophyceae) is therefore more readily removed when activated silica is used.

Experimental Work

The remainder of this article is devoted to reporting the experimental work performed at Brantford and to an evaluation of the data.

Slow Sand Filter

A small experimental slow sand filter was operated for a two-month period during which the free NH_3 content of the water was virtually zero and the protein content was high. With almost zero turbidity, the protein content would be in colloidal solution. The water layer above the sand maintained anaerobic conditions within the filter. This experiment was undertaken to determine whether protein matter was destroyed by bacteria living within the filter under such conditions.

The applied and effluent waters were examined periodically for free NH_3, albuminoid NH_3, total organic nitrogen, chlorine demand to produce free residual chlorination, taste, odor, pH and dissolved oxygen. The results were not very encouraging because of the occurrence of septic conditions within the filter after a few days of operation. Although some oxygen was present in the applied water, the filter effluent exhibited a high oxygen demand.

The odor of the filter effluent was many times that of the applied water and was of a type that could not be removed by free residual chlorination, requiring abnormal dosages of activated carbon for removal. Some protein was converted to free NH_3, but this exchange resulted in very little reduction in chlorine demand. Most of the protein remained in the water after slow sand filtration indicating that the process is unsuitable for removal of protein from a highly polluted river.

Oxidation

Attempts were made to oxidize proteins by aerating the water with air and with pure oxygen. An abundant supply of oxygen was expected to intensify the activity of aerobic bacteria in the water and thereby increase their efficiency in protein oxidation. Some samples were aerated for from three hours to ten days, and one sample was continuously aerated for 30 days. In other aeration experiments, small quantities of the sample would be replaced daily with an equal amount of fresh raw water to introduce new life. These experiments

provided the conditions necessary for oxidation: the presence of natural life, light and abundant oxygen. The tests were designed to determine whether natural bacteria, aided only by oxygen, would oxidize proteins. Nitrates were therefore not added as supplementary bacterial food. All the results indicated that the protein content of the water remained unchanged.

Activated Sludge

In a variation of the aeration procedure, an attempt was made to operate an experimental activated sludge process. Pure oxygen was applied instead of air. Each day a portion of the sample would be replaced by an equal volume of fresh raw water. Two months' operation showed that an active sludge could not be built up from the natural constituents of the raw water.

Repetition of this experiment produced a massive sludge by the addition of alum, ferric chloride, clay and river mud. This sludge was removed and washed with a number of samples of raw river water to make sure all unreacted alum and ferric chloride had been removed. Fresh raw river water was then added and aeration with pure oxygen started. The aeration was stopped each day, but only long enough to permit separation of the water and sludge layer. Most of the water was then drawn off, fresh raw water added, and the aeration continued. One month of this treatment was considered ample time for the development of biological activity in the sludge.

On the final day, a new sample was added and permitted to aerate for 24 hours. A second sample was left untreated as a control, and a third sample was rapidly coagulated with excess lime, and then settled and filtered. The following day all three samples were analyzed for total organic nitrogen. The excess lime treatment exhibited its usual ability to accomplish high protein removal, matching the results obtained from the activated sludge precisely.

The results indicate that abundant oxygen and a biologically active sludge do not affect protein removal. Both excess lime and activated sludge treatment of water removed protein apparently only by the absorptive effect of a massive floc. These results again emphasize that the continuation and improvement of present coagulation procedures appear more promising for removal of protein from water than does bioactivity. As excess lime and activated sludge gave the same results, the choice of process becomes a matter of economy.

Biological Filter

Pugh (9) operated a trickling filter for pretreatment of raw water before coagulation and free residual chlorination. His results demonstrated that such a filter removed large proportions of free NH_3, bacteria, nitrites and phenols. A large chlorine demand reduction was accomplished in the treatment of a raw water having much free NH_3. For treatment of a river in which free ammonia constitutes the major chlorine demand, a filter of this type would seem desirable, although in colder climates, prevention of freezing of the filter and provision for suitable housing present problems.

He did not state whether his biological filter accomplished a decrease in protein content (as indicated by either the albuminoid NH_3 or the total organic nitrogen by Kjeldahl procedures). Despite the presence of other pollution, the Avon River which provided the water for Pugh's studies may

be relatively free of protein matter. His work has therefore been repeated at Brantford to determine whether a biofilter will oxidize or, in some manner, reduce the protein content.

The experimental biofilter employed at Brantford had a surface area of 18 × 18 in., a bed depth of 5 ft., was filled with coke of 1–2 in. size and was ventilated by louvre type sides made of 3½-in. pine boards spaced 1 in. apart, slanting upwards and outwards at a 45-deg. angle. This filter was operated by applying water at a rate of 1 gph. (Imp.) per sq.ft. a very low rate of operation compared with Pugh's 36 gph. (Imp.) per sq.ft. The filter was operated continuously from August 3, 1950, to January 15, 1951.

No attempt was made to determine the effect of this filter upon nitrites, phenols, chlorine demand, bacteria, pH or amenability of the treated water to coagulation. The study was restricted to investigating the possible biological removal of protein. The free NH_3 was determined and removed before determining albuminoid NH_3 and total organic nitrogen contents.

The results may be summarized as follows:

1. Pugh's claim for reduction of free NH_3 content was well substantiated, with reductions amounting to approximately 50 per cent. If free NH_3 is always present and constitutes a high chlorine demand, a biofilter will be valuable in reducing the costs of free residual chlorination. In Pugh's experiments, the chlorine demand of 37 ppm. was reduced to approximately 6 ppm. At Brantford, where free NH_3 is present in very small amounts for all but 10–20 days annually, the capital expenditure and the operating costs of such a filter would greatly exceed the cost of the extra chlorine required during brief periods when free NH_3 is high. The chlorine demand at Brantford is due mainly to protein, which would make installation of such a filter unwise on the basis of the free NH_3 removal accomplished.

2. The effect of the filter upon protein is shown in Fig. 2, in which curve *A* represents the total organic nitrogen content of the applied water (containing protein in colloidal solution and also varying amounts of protein in suspension). Curve *B* represents the total organic nitrogen content of raw water samples, identical with applied samples and filter effluent samples, which were filtered through glass wool to remove suspended matter prior to analysis. Curve *C* represents the total organic nitrogen content of the biofilter effluent.

These results show that rapid filtration through glass wool and filtration through a biofilter are, for all practical purposes, identical in their removal of suspended protein. Such removal has been previously indicated to be a minor problem if adequate coagulation, settling and filtration are applied. Neither rapid filtration through glass wool nor slow filtration through a biofilter accomplishes removal of protein in colloidal solution. The biofilter is therefore, in effect, merely a screen to retain suspended protein and an ineffective agent for reducing soluble protein. The biological growth within the filter apparently does not utilize protein.

Even the screening effect of a biofilter is of limited duration, since the filter will become clogged or will unload. Pugh mentions sloughing, which was also noticed in the Brantford work. During sloughing, considerable suspended organic matter—greatly in excess of that found in the raw water at

any given time—would unload from the filter for several hours at a time. Removal of suspended organic matter represents a temporary retention of protein. Inorganic turbidity will also be retained temporarily. No analyses were made during sloughing periods as only oxidation of colloidal protein was to be determined. Because the oxidation was not accomplished, the use of such a filter for pretreatment of Grand River water was not considered.

Effect on Amino Acids

The work of Feben and Taras (13, 14) in determining the chlorine demand constants of natural waters containing organic nitrogen compounds and of waters to which pure amino acids had been added greatly increased knowledge of chlorination. Because the mixture of unknown amino acids and proteins naturally found in water is reduced in concentration by chemical coagulation, it appeared desirable to determine whether amino acids artificially added to water would be removed by the same type of coagulation.

Samples of raw water containing natural proteins and samples of the same water to which amino acids had been added were subjected to analysis for free NH_3, albuminoid NH_3 and total organic nitrogen by the Kjeldahl method. An identical set of samples, representing the natural water and that to which amino acid had been added, was treated by the various types of coagulation previously described, settled, filtered and then analyzed for the nitrogen compounds. The basic sample of water, which provided all the portions used, was filtered through glass wool. This treatment removed suspended organic matter and reduced the problem for consideration to removal of protein in colloidal solution. The amino acids tryptophane, histidine, tyrosine, arginine and cystine * were selected in view of their use in the Feben and Taras (13, 14) work and also their mention by Whipple and Fair (6). For brevity, the results for tyrosine only have been presented in

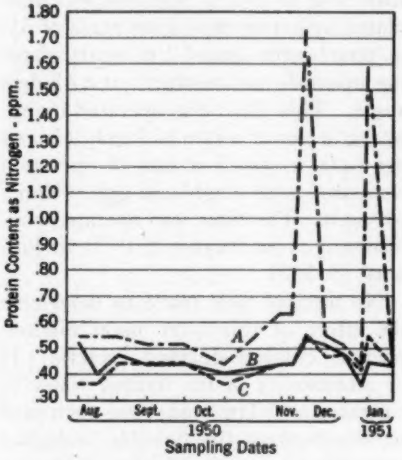

Fig. 2. Effect of Filter on Protein

Curve A *represents total organic nitrogen content (existing as a colloid and in suspension) of the applied water; Curve* B, *the total organic nitrogen content of raw water samples identical with applied samples and filter effluent samples filtered through glass wool to remove suspended matter before analysis; Curve* C, *total organic nitrogen content of biofilter effluent. Rapid filtration through glass wool and through a biofilter effect almost identical protein removal.*

Fig. 3. From this work it is apparent that:

1. Amino acids added to a water behave, under conditions of chemical coagulation, in a manner identical with

* Amino acids of the grades specified by Eastman Kodak Co., Rochester, N.Y.

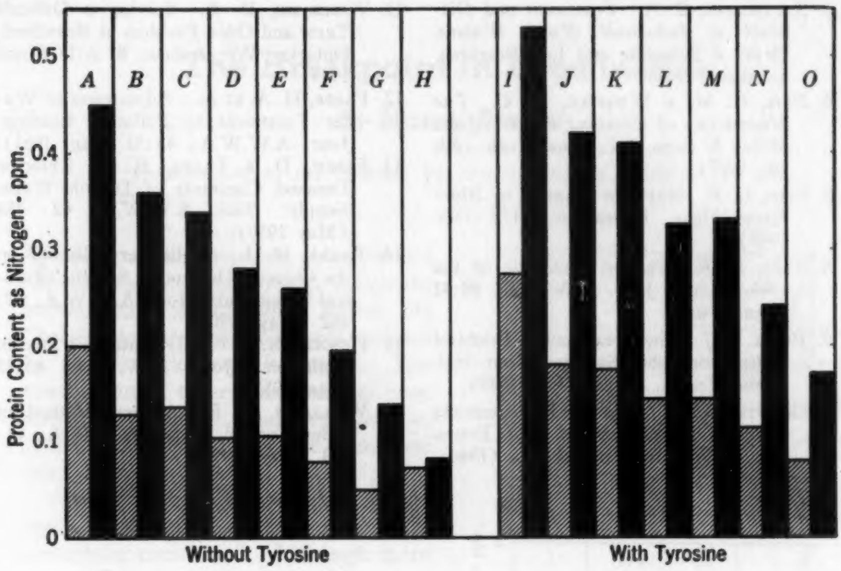

Fig. 3. Effect of Amino Acids on Protein Removal in Coagulation

The amino acid used in the experiment represented here is tyrosine. The cross-hatched bars represent albuminoid NH_3, and the solid bars represent total organic nitrogen.

Key

A—Basic sample (raw water plus simple filtration)
B—Basic sample plus 3 grains alum
C—Basic sample plus 3 grains ferric chloride
D—Basic sample plus 6 grains alum
E—Basic sample plus 6 grains ferric chloride
F—Basic sample plus excess lime
G—Basic sample plus superexcess of lime
H—Nitrogen-free distilled water plus 1 ppm. tyrosine
I—Basic sample plus 1 ppm. tyrosine
J—Basic sample plus 3 grains alum and 1 ppm. tyrosine
K—Basic sample plus 3 grains ferric chloride and 1 ppm. tyrosine
L—Basic sample plus 6 grains alum and 1 ppm. tyrosine
M—Basic sample plus 6 grains ferric chloride and 1 ppm. tyrosine
N—Basic sample plus excess lime and 1 ppm. tyrosine
O—Basic sample plus superexcess of lime and 1 ppm. tyrosine.

the mixture of amino acids and proteins naturally occurring in waters.

2. As with naturally occurring nitrogen complexes, the added amino acids are only partially removed. The extent of removal depends on the coagulant and coagulation technique employed.

3. The procedure provides a practical method of adding controlled amounts of organic nitrogen to water for the purpose of evaluating removal procedures.

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The Breakpoint in Bromination

By Maxey Brooke

A contribution to the Journal by Maxey Brooke, Phillips Oil Co., Sweeney, Tex.

THE reaction between chlorine and ammonium compounds, which involves what is commonly called the "breakpoint process," has been utilized by water works men for years. The mechanism of these reactions has been thoroughly studied and reported, so that the concept has become a familiar one.

Among other bactericidal agents used in treating water, bromine is sometimes mentioned. Although there are no known applications of bromine to public water supplies, it is finding occasional and increasing use in swimming pools and industrial water supplies. Because the chemical is used in water conditioning, it was considered desirable to explore its reactions with ammonium compounds to determine if there is a "breakpoint" analogous to the chlorine reactions.

Tests were conducted in the usual manner. To an ammonium hydroxide solution containing 0.5 ppm. ammonia nitrogen, there were added varying quantities of bromine water to give the desired bromine application. The solutions were buffered with disodium phosphate or monopotassium phosphate. The mixtures were stirred for 30 minutes, and the resulting bromine and ammonia nitrogen residuals were determined.

The bromine residual was determined with orthotolidine using a Taylor bromine slide comparator. It was not possible to distinguish between the

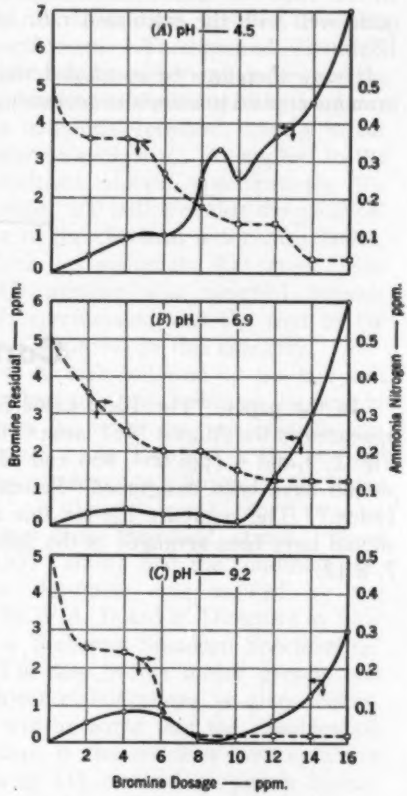

Fig. 1. Bromine Breakpoints.

Reaction time was 30 minutes. At low pH (A) bromine curve follows pattern similar to a chlorine curve. At neutral pH (B) bromine curve shows minimum break; a chlorine curve would show maximum. At high pH (C) bromine curve shows clear break; a chlorine curve would show almost none.

free bromine and combined bromine residuals by means of the orthotolidine-arsenite test, so all residuals reported are total bromine residuals.

The ammonia nitrogen residual was determined with Nessler reagent using a Taylor water analyzer.

The break occurs in the range of a Br : N ratio of 20 : 1, which agrees quite well with the calculated ratio of 17 : 1.

It may therefore be concluded that bromine applied to ammonia-containing water shows the same general break-point phenomenon as does chlorine. This correlation can be seen by comparing Curves *A, B,* and *C* in Fig. 1 with the curves supplied by Connell (1).

Reference

1. Connell, C. H. Orthotolidine Titration Procedure for Measuring Chlorine Residuals. Jour. A.W.W.A., **39**:209 (Mar. 1947).

Correction

In the paper, "The Ideal Lime-Softened Water," by T. E. Larson, which appeared in the August 1951 issue of the Journal, the ordinates of the graphs in Fig. 2, 3 and 4 (pp. 654, 656 and 658) were incorrectly labelled. These axes should have been designated "Saturation Index Change" instead of "Stability Index." The reference list for this article became scrambled. The references should have been arranged in the following order: 1, 10, 9, 11, 12, 2, 3, 4, 5, 6, 7, 8 13.

New System for Designating A.W.W.A. Standards

DESIGNATIONS for specifications, unless carefully planned for the future, have a tendency to become outmoded as the number and type of specifications increase. For some time it has been apparent that the A.W.W.A. designation code has not kept pace with the diversity of standards documents developed. The practice of identifying specifications by the symbol of the committee that prepared them did not result in a system with a coherent and orderly relation between specifications of similar content and scope.

Correction of this condition has involved a complete change in designation system. To avoid confusion and minimize the difficulties of making the change, all previously issued standards will carry both old and new designations for several years. The cover pages of existing stocks have been overstamped with the new designation, and new printings will show the old designation beneath the new one. Specifications which have never been assigned a number under the old system, such as the one for reinforced concrete pipe which appears elsewhere in this issue, will show only the new number.

The new system is exemplified by the aluminum sulfate designation, which is AWWA B400–50T. The component letters and numbers derive from the application of the following system:

1. The letters "AWWA" are used to identify the source of all American Water Works Association standards.

2. An initial letter designates each of the main groups into which the body of standards is classified. The letter "B" designates all documents dealing with water treatment.

3. A three-digit number identifies specific items. The hundreds digit designates major subject categories, and the tens and units digits together designate the individual standard, usually in the order promulgated. As applied to the aluminum sulfate specifications, the number 400 indicates that the principal use of the chemical is for coagulation, which lies within the 400 series. The "00" number was assigned because this specification was the first to receive approval in this category.

4. A dash followed by the last two numbers of a year indicates the year in which the document was officially approved, made Standard or last revised. The numbers are followed by the letter "T" if the document has Tentative rather than Standard status. Thus "–50T" shows that the aluminum sulfate document was ratified by the A.W.W.A. Board of Directors in 1950 as a Tentative Standard Specification.

The key to the major groups and subject classifications is given below. It will be noted that the classification system is the result of compromising among [1] division on purely logical, functional principles, [2] the necessity to separate certain subjects (such as that of pumps), which could otherwise be considered under more than one of the other major groups, and [3] the practical need to assign relatively large blocks of numbers to subjects upon which many standards are or may be prepared. The choice among conflict-

ing categories into which a particular standard might be placed is generally resolved by choosing the principal and customary one—for example, specifications for chlorine would be included in the disinfection category, although the chemical is also used for taste and odor control. Additional assignment of letter and number groups may be made in the future, as the activities of the Association warrant.

A—Source

Wells, intakes, watersheds

B—Treatment

B100	Filtration
B200	Softening
B300	Disinfection *
B400	Coagulation
B500	Scale and corrosion control
B600	Taste and odor control
B700	Prophylaxis

C—Distribution

C100	Cast-iron pipe and fittings
C200	Steel pipe
C300	Reinforced concrete pipe
C400	Asbestos-cement pipe *
C500	Valves and hydrants
C600	Pipelaying
C700	Meters
C800	Service lines
C900	Records and general

D—Storage

Storage tanks, standpipes and reservoirs

E—Pumps *

Pumps and controls

F—Special Water-Using Equipment *

Air conditioning, sprinkling systems

G—Analysis †

Standard methods for the examination of water

H—Administration *

Organization, policy, public relations, compensation, safety practices

J—Sales and Rates *

Accounting, billing, depreciation, financing

* As yet no specifications in this category have been completed.

† Standards in this category are currently published in book form as *Standard Methods for the Examination of Water and Sewage.*

American Water Works Association

Tentative

STANDARD SPECIFICATIONS

for

REINFORCED CONCRETE WATER PIPE—NONCYLINDER TYPE, NOT PRESTRESSED

These "Tentative Standard Specifications for Reinforced Concrete Water Pipe—Noncylinder Type, Not Prestressed" are based upon the best known experience and are intended for use under normal conditions. They are not designed for unqualified use under all conditions and must be reviewed by the engineer responsible for the construction and modified as necessary to meet specific conditions pertaining to each individual installation.

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Tentative Specifications for

Reinforced Concrete Water Pipe—Noncylinder Type, Not Prestressed

Section 1—General

Sec. 1.1—Scope

These specifications cover the manufacture of reinforced concrete pressure pipe, without steel cylinder and not prestressed, in sizes from 12 in. to 96 in. inclusive, designed for service where the maximum design head shall not exceed 100 ft. and for such external loading conditions as may be designated by the purchaser. This type of pipe has been extensively used on low-head transmission work, reservoir connections and lines not subject to possibility of higher heads or shock but has been little used and is not recommended for other than very special conditions in distribution system work.* The specifications do not include delivery, laying, field testing or sterilization of the pipe.

Sec. 1.2—Definitions

In these specifications the following definitions will apply:

1.2.1 *Purchaser.* The word "purchaser" shall mean a person, firm, corporation or governmental subdivision entering into a contract or agreement to purchase any materials, or have any work performed, according to these specifications.

1.2.2 *Contractor.* The word "contractor" shall mean the person, firm or corporation executing the contract or agreement with the purchaser to furnish any materials or perform any work according to these specifications.

1.2.3 *Manufacturer.* The word "manufacturer" shall mean the person, firm or corporation who actually manufactures the pipe, acting either directly as the contractor or as a subcontractor. If the manufacturer is acting as a subcontractor under the contractor, the obligations of the manufacturer under these specifications shall be considered as obligations of the contractor, and the contractor shall be responsible for their performance.

1.2.4 *Engineer.* The word "engineer" shall mean the engineer employed by the purchaser and acting as the purchaser's representative; the purchaser himself, acting as his own engineer; and their respective assistants and inspectors.

1.2.5 *A.S.T.M.* The term "A.S. T.M." shall mean the American Society for Testing Materials. When specific A.S.T.M. specifications are cited, the designation shall be construed to refer to any subsequent revision under the same specification number, or superseding specifications under a new number, except as to provisions in the revised specifications which clearly are inapplicable.

1.2.6 *Approved.* The term "approved" shall mean having received the approval of the engineer.

1.2.7 *Internal Pressures.* The term "internal pressures" shall mean hydrostatic pressures imposed on and applied to the interior of the pipe by the design head specified by the purchaser.

Internal pressures shall be expressed in pounds per square inch.

1.2.8 *External Loads.* The term "external loads" shall mean all superimposed live and dead loads applied to the pipe after installation and shall be independent of any and all hydrostatic pressures within the pipe. External loads shall be expressed in pounds per linear foot of pipe.

Sec. 1.3—Essential Requirements

The pipe shall have the following principal features: a reinforcing cage or cages of steel rods, bars, wire or fabric; a wall of dense concrete covering the reinforcing cage or cages inside and out; and approved type of joint with a preformed gasket or gaskets of rubber so designed that the joint will be watertight under all normal conditions of service.

Sec. 1.4—Plans and Data Furnished by Purchaser

The purchaser shall designate the total head or resulting internal pressure for which the pipe shall be designed. If the pipe is to be used under conditions where the superimposed external loads will be a determining factor in the design of the pipe, the purchaser also shall designate the external load or details of external loading conditions for which the pipe shall be designed. If the contractor is required to vary the design of the pipe for specific conditions in accordance with its location in a pipe line, the purchaser shall furnish to the contractor plans and profiles of the pipe line showing: alignment and grades; the location of all outlets, connections and special appurtenances; the design head and external loads or the required cross-sectional area of effective circumferential reinforcement per foot of pipe wall for each portion of the pipeline; and such special details as are necessary for the manufacture of the pipe and fittings in accordance with these specifications and with the specific requirements of the work for which the particular pipe is made.

Sec. 1.5—Supplementary Details Specified by Purchaser

When purchasing pipe under these specifications, it will be necessary for the purchaser to make supplementary statements specifying: the manner of storage and delivery if these are required of the contractor or manufacturer; and the type of specials and fittings to be furnished.

Sec. 1.6—Data Submitted by Contractor

1.6.1 Drawings and schedules showing full details of reinforcement, concrete and joint dimensions for the pipe shall be furnished by the contractor. All drawings and schedules shall be submitted for approval in quadruplicate, and one copy shall be returned to the contractor after approval. No pipe shall be maufactured until the drawings have been approved.

1.6.2 If specifically required, the data submited by the contractor shall include a tabulated layout schedule, with reference to the stationing and grade line shown on the contract drawings. The schedule shall show pressure and external loading zones, each of which shall be designated by the design head and external load applicable therein, and the point of change from one zone to the next shall be clearly indicated by station number. The diameter of pipe, the design head, the external load, and the thickness of pipe wall and area of steel (per linear foot of pipe) in the reinforcing rods or wire shall be listed

for each portion of pipe line for which the design head or the equivalent internal pressure and the external load is fixed by the purchaser.

Sec. 1.7—Marking

Each special and each length of straight pipe shall have plainly marked on the bell end the identification marks specified by the purchaser. These shall include, as specified, either the head and external load for which the pipe or special is designed or the area of effective circumferential reinforcement per foot of pipe wall. Special marks of identification, sufficient to show the proper location of the pipe or special in the line by reference to layout drawings and schedules specified under Sec. 3–1.6 of these specifications, shall be placed on the pipe if required. All beveled pipe shall be marked with the amount of the bevel. If elliptical reinforcing is used, the minor axis of the reinforcing shall be designated on the interior surface of the bell end of the pipe.

Sec. 1.8—Inspection

1.8.1 The purchaser and his representatives shall have access to the work wherever it is in preparation or progress, and the contractor shall provide proper facilities for access and for inspection.

1.8.2 Inspection by the purchaser or his representatives, or failure of the purchaser or his representatives to provide inspection, shall not relieve the contractor of his responsibility to furnish materials and to perform work in accordance with these specifications.

1.8.3 Material, fabricated parts and pipe which are discovered to be defective or which do not conform to the requirements of these specifications, will be subject to rejection at any time prior to final acceptance of the pipe. Rejected material and pipe shall promptly be removed from the site of the work.

Sec. 1.9—Material and Workmanship

All material furnished by the contractor shall be new and of the quality specified. All work shall be done in a thorough, workmanlike manner by mechanics skilled in their various trades.

Sec. 1.10—Tests

1.10.1 The contractor shall furnish, in advance of manufacture of reinforcing cages, mill test reports on each heat from which the steel is rolled, if required.

1.10.2 The contractor shall provide test specimens cut on the job from each shipment of steel for reinforcing as directed by the engineer.

1.10.3 Welds in reinforcing rods or bars shall be tested as specified under Sec. 3–3.5.

1.10.4 Frequent samples of mixed concrete shall be taken for making up compression test cylinders as specified under Sec. 3–3.6.

1.10.5 If required by the engineer, the contractor shall submit test results showing the chemical and physical properties of rubber used in the gaskets.

1.10.6 The expense of the required mill tests of materials, and of testing the welds in the reinforcing shall be borne by the contractor. All other tests shall be made by representatives of the purchaser at the purchaser's expense, except as otherwise specifically provided.

Section 2—Material Specifications

Sec. 2.1—Cement

2.1.1 Cement for concrete work shall conform to the "Standard Specifications for Portland Cement, Type I or Type II," (A.S.T.M. Designation C150). Sampling and testing shall conform to the individual A.S.T.M. specifications designated therein.

2.1.2 Satisfactory facilities shall be provided for identifying, inspecting and sampling cement at the mill, the warehouse and the site of the work. The purchaser shall have the right to inspect the cement and obtain samples for testing at any of these points.

2.1.3 Cement shall be stored in a weather-tight, dry, well ventilated structure approved by the engineer.

2.1.4 Cement salvaged by cleaning cement sacks, mechanically or otherwise, shall not be used in the work. Cement containing lumps will be rejected and shall immediately be removed from the site of the work.

2.1.5 If the temperature of the cement exceeds 150°F., it shall be stored until cooled to that temperature.

Sec. 2.2—Fine Aggregate

2.2.1 Fine aggregate for concrete and mortar shall consist of clean, hard, durable and uncoated particles of natural sand or sand prepared from the product obtained by crushing stone, gravel or other inert materials having similar qualities. The type of material shall be subject to the approval of the engineer. At the time of use the fine aggregate shall be entirely free of frozen material.

2.2.2 Fine aggregate shall be free from organic impurities to the extent that, when subjected to the color test for organic impurities, it shall produce a color in the sodium hydroxide solution not darker than that of Fig. 2 in the "Standard Method of Test for Organic Impurities in Sands for Concrete" (A.S.T.M. Designation C40).

2.2.3 Fine aggregate shall be of such quality that mortar composed of it, when tested by the "Standard Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement Ratio Mortar" (A.S.T.M. Designation C87), shall have a compressive strength equal to that of similar specimens—of the same proportions and composed of the same cement and Ottawa sand—graded as specified in the "Method of Test for Compressive Strength of Hydraulic-Cement Mortars" (A.S.T.M. Designation C109).

TABLE 1

Gradation Requirements for Fine Aggregate

Sieve Size	Total Passing, by Weight *per cent*
$\frac{3}{8}$ in.	100
No. 4	95–100
No. 8	65–98
No. 16	45–80
No. 30	20–70
No. 50	5–50
No. 100	2–10
No. 200	0–5

2.2.4 Fine aggregate shall be well graded from coarse to fine and, when tested by means of laboratory sieves in accordance with the "Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates" (A.S.T.M. Designation C136), shall conform to the gradation requirements in Table 1.

The gradation requirements given in Table 1 represent the extreme limits for determining the suitability of fine aggregate under these specifications.

To maintain uniformity of gradation for aggregate from any given source, a fineness modulus determination shall be made upon representative samples from that source. Thereafter, the fineness modulus of all shipments therefrom shall not vary more than ± 0.20 from the fineness modulus of the representative sample.

Sec. 2.3—Coarse Aggregate

2.3.1 Course aggregate for concrete shall consist of hard, durable particles of crushed stone or crushed or uncrushed gravel conforming to the requirements and tests given in paragraphs 2.3.2 through 2.3.5.

2.3.2 Coarse aggregate shall be well graded from coarse to fine. The maximum size and gradation shall be subject to the approval of the engineer and shall be such that the concrete can be readily placed inside the mold, by the particular method used in placing it, to provide a solid, compact, homogeneous wall with a smooth surface. Tests for gradation of coarse aggregate shall be in accordance with the "Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregate" (A.S.T.M. Designation C136).

2.3.3 Deleterious substances in coarse aggregate shall not exceed the amounts given in Table 2 as determined by sampling and testing procedures listed in the "Standard Specifications for Concrete Aggregates" (A.S.T.M. Designation C33).

2.3.4 Thin and elongated pieces, the maximum dimension of which exceeds five times the minimum, shall not be in excess of 10 per cent of the coarse aggregate by weight.

2.3.5 The coarse aggregate, when subjected to five alternations of the sodium sulfate test in accordance with the "Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate" (A.S.T.M. Designation C88), shall have a corrected loss not in excess of 12 per cent unless specifically permitted by the engineer.

Sec. 2.4—Samples of Concrete Aggregates

At least four weeks prior to mixing concrete, the contractor, if required, shall deliver in suitable containers, for preliminary approval, samples of not less than 1 cu.ft. each of fine aggregate and coarse aggregate. All samples shall be plainly labeled to indicate the source of the material, the date and the name of the collector. Methods of sampling aggregates shall be in accordance with the "Tentative Methods of Sampling Stone, Slag Gravel, Sand and Stone Block for Use as Highway Materials" (A.S.T.M. Designation D75).

TABLE 2

Permissible Amounts of Deleterious Substances in Course Aggregate

Material	Max. Weight Limit *per cent*
Soft particles	4.00
Coal and lignite	0.50
Clay lumps	0.25
Material finer than 200 sieve	1.00
Combined total of above items	5.00

Sec. 2.5—Water

Water used for concrete and for curing pipe shall be clean and free from oil, acid, strong alkalies or vegetable matter, and the source shall be approved by the engineer.

Sec. 2.6—Steel for Reinforcement

2.6.1 Rods or bars for reinforcement of concrete shall conform to the "Stand-

ard Specifications for Billet-Steel Bars for Concrete Reinforcement, Structural Grade" (A.S.T.M. Designation A15). Steel wire for reinforcement of concrete shall conform to the "Standard Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement" (A.S.T.M. Designation A82). Wire fabric for reinforcement of concrete shall conform to the "Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement" (A.S.T.M. Designation A185).

2.6.2 Wire fabric reinforcement for mortar coating of fittings shall conform to the "Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement" (A.S.T.M. Designation A185).

2.6.3 Steel rod or bar reinforcement for concrete for fittings shall conform to "Standard Specifications for Billet-Steel Bars for Concrete Reinforcement, Structural Grade" (A.S.T.M. Designation A15).

Sec. 2.7—Steel for Joint Rings

In joint designs incorporating metal joint rings, the following shall apply:

2.7.1 Steel strips for bell rings less than $\frac{1}{4}$ in. thick shall conform to "Tentative Specifications for Hot-Rolled Strips of Structural Quality" (A.S.T.M. Designation A303).

2.7.2 Steel plate for bell rings $\frac{1}{4}$ in. or more in thickness shall conform to the "Tentative Specifications for Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality" (A.S.T.M. Designation A283).

2.7.3 Special shapes for spigot joint rings shall conform to the "Standard Specifications for Boiler Rivet Steel and Rivets (A.S.T.M. Designation A31), except that paragraph 7 (b) shall be waived, or to the "Tentative Specifications for Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality" (A.S.T.M. Designation A283).

Sec. 2.8—Steel Castings for Fittings

Steel castings for fittings shall conform to the "Tentative Specifications for Mild to Medium Strength Carbon-Steel Castings for General Application, Grade 70–36, Normalized" (A.S.T.M. Designation A27).

Sec. 2.9—Steel Sheets for Specials and Fittings

Steel sheets for specials and fittings shall conform to the "Tentative Specifications for Heavy Gage Structural Quality Flat Hot-Rolled Carbon Steel, Open Hearth, Grade B" (A.S.T.M. Designation A245).

Sec. 2.10—Steel Plates for Specials and Fittings

Steel plates for specials and fittings shall conform to the "Tentative Specifications for Low and Intermediate Tensile Strength Carbon-Steel Plates of Structural Quality, Grade B or C" (A.S.T.M. Designation A283).

Section 3—Fabrication of Pipe

Sec. 3.1—General Requirements

3.1.1 In general pipe shall have a minimum length of 8 ft. except for bends, reducers, closure pieces and other special fittings which may be made in shorter lengths. The maximum lengths shall be as follows:

Size—*in.*	Max. Length—*ft.*
12–15 (inclusive)	8
16–21 (inclusive)	12
24 and larger	16

3.1.2 Pipe shall be round and true and shall have smooth and dense finished surfaces. The mean internal diameter of any portion of each section of pipe shall not fall short of the nominal diameter or size specified by more than 1.0 per cent if the pipe is 48 in. or smaller, or by more than 0.75 per cent if the pipe is 54 in. or larger. The wall thickness shall not have a minus variation of more than 5 per cent from the nominal thickness shown in Table 3.

3.1.3 The minimum wall thickness, the minimum and maximum center-to-center spacing of circumferential reinforcement and the number of circumferential reinforcing cages for each size of centrifugal and vertically cast pipe shall be as shown in Table 3.

Sec. 3.2—Design of Steel Reinforcement

The reinforcement of the pipe shall consist of one or more cages of welded steel hoops, helically wound steel rods, wire, or welded fabric properly spaced and supported with longitudinal reinforcing. Each cage shall have a minimum longitudinal reinforcement equivalent to $\frac{1}{2}$-in. round steel rods at a maximum spacing of 30 in. center-to-center, except that no cage shall have less than six rods of at least $\frac{1}{4}$-in. diameter. The combined cross-sectional area of circumferential steel in the reinforcement cage or cages shall be such that the steel will not be stressed in excess of 12,500 psi. when the pipe is subjected to an internal pressure equivalent to the hydrostatic head or pressure

TABLE 3

Requirements for Pipe of Various Sizes

Pipe id. *in.*	6,000-psi. Centrifugal Concrete		4,500-psi. Poured Concrete		Circumf. Reinf. Spacing *in.*	
	Min. Pipe Wall Thickness *in.*	Min. No. of Cages	Nominal Pipe Wall Thickness *in.*	Min. No. of Cages	Min.	Max.
12	2	1	—	—	$1\frac{1}{4}$	4
15	2	1	—	—	$1\frac{1}{4}$	4
16	$2\frac{1}{8}$	1	—	—	$1\frac{1}{4}$	4
18	$2\frac{1}{4}$	1	—	—	$1\frac{1}{4}$	4
20	$2\frac{3}{8}$	1	—	—	$1\frac{1}{4}$	4
21	$2\frac{3}{8}$	1	—	—	$1\frac{1}{4}$	4
24	$2\frac{1}{2}$	1	$3\frac{1}{2}$	1	$1\frac{1}{4}$	4
27	$2\frac{5}{8}$	1	$3\frac{1}{2}$	1	$1\frac{1}{4}$	4
30	$2\frac{3}{4}$	1	$3\frac{1}{2}$	1	$1\frac{1}{4}$	4
33	$2\frac{7}{8}$	1	4	2	$1\frac{1}{4}$	4
36	3	1	4	2	$1\frac{1}{4}$	4
42	$3\frac{1}{2}$	2	$4\frac{1}{2}$	2	$1\frac{3}{4}$	5
48	4	2	5	2	$1\frac{3}{4}$	5
54	$4\frac{1}{2}$	2	$5\frac{1}{2}$	2	$1\frac{3}{4}$	5
60	5	2	6	2	$1\frac{3}{4}$	5
66	$5\frac{1}{2}$	2	$6\frac{1}{2}$	2	$2\frac{1}{4}$	6
72	6	2	7	2	$2\frac{1}{4}$	6
84	7	2	8	2	$2\frac{1}{4}$	6
96	8	2	$8\frac{1}{2}$	2	$2\frac{1}{4}$	6

fixed by the purchaser, with no allowance for the tensile strength of the concrete. Reinforcement for pipe for use in heavy traffic or deep trenching conditions in which the external loading is a determining factor in the design shall be designed for combined internal and external loading designated by the purchaser. The details of the design and reinforcement shall be submitted for approval by the purchaser. The circumferential steel for all sizes of pipe shall be at least the equivalent of the amount shown in Table 1 for 4,500-psi. concrete of A.S.T.M. Specification C76 for "Standard-Strength Reinforced Concrete of Culvert Pipe."

Sec. 3.3—Joints

The contractor shall submit with his bid details of the joints to be furnished. The joints shall be of the round rubber gasket type using either a bell-and-spigot joint design or a double spigot and sleeve joint design of concrete or steel. In either type, the joints shall be so designed that when the pipe is laid and the joint completed, the gasket will be enclosed on all four surfaces. The joints shall be so designed and fabricated that when the pipe is laid, it will be self-centering and the gasket or gaskets shall not be required to support the weight of the pipe, but shall keep the joint tight under all normal conditions of service, including expansion, contraction and normal earth settlement. The bell and spigot surfaces of the pipe shall be accurately formed to provide closely fitting joints. The tolerance between the theoretical diameters and the actual diameters of the contact surfaces shall be such that the average clearance shall not exceed $\frac{1}{16}$ in. If the joints are fabricated employing steel bell-and-spigot joint rings or a steel sleeve, each ring shall be formed by one or more pieces of steel, which are butt-welded together either by a resistance weld or by hand electric arc weld. After welding the ring shall be smoothed by grinding the rough surfaces of the weld flush with the adjacent surfaces. The rings shall be expanded by a press beyond their elastic limits so that they are accurately shaped. They shall be checked for size and shape on accurate templates before being incorporated in the pipe. The minimum thickness of the completed bell or spigot ring shall be $\frac{3}{16}$ in. The ring shall conform to the details submitted by the manufacturer and approved by the engineer. The contact surfaces shall be smooth to prevent cutting of the rubber gasket during installation. The portions of the joint ring which will be exposed after the pipe is cast shall be protected from corrosion by an approved metallic coating with a minimum thickness of 0.002 in. applied by an approved method. When specifically permitted, an approved nonmetallic coating may be used.

Sec. 3.4—Rubber Gaskets

3.4.1 The joint shall be sealed with a continuous-ring gasket made of a special composition rubber of such size and cross section as to fill completely the recess provided for it. The gasket shall be the sole element depended upon to make the joint watertight and shall have smooth surfaces free from pits blisters, porosity and other imperfections. The rubber compound shall contain not less than 50 per cent by volume of first grade natural crude or first grade synthetic rubber. The remainder of the compound shall consist of pulverized fillers free from rubber substitutes, reclaimed rubber and deleterious substances. The compound

shall meet the following physical requirements when tested in accordance with appropriate sections of "Methods of Physical Tests and Chemical Analyses for Rubber Goods" (Federal Specification ZZ–R–601):

Tensile strength. The tensile strength of the compound shall be at least 2,700 psi. for natural rubber gaskets and 1,700 psi. for synthetic rubber gaskets.

Elongation at rupture. Two-in. gage marks shall stretch to not less than 9 in. at rupture.

Specific gravity. The specific gravity shall be between 1.15 and 1.25.

Cold flow test. The proportion of cold flow—computed as 100 times the change in thickness divided by the original thickness—shall not exceed 12 when tested by subjecting a disk of the material, $\frac{1}{4}$ in. thick by $\frac{3}{4}$-in diameter, to a pressure of 600 psi. using a spring-pressure device placed in an air oven at a temperature of 158°F. for 24 hours.

Tensile strength after aging. The tensile strength of the compound, after being subjected to an accelerated aging test for 96 hours in air at 158°F., shall not be less than 80 per cent of the tensile strength before aging. The test shall be that described in "Methods for Testing Rubber Goods" (Federal Specication ZZ–R–601, Sec. 2, Par. 14).

3.4.2 The contractor shall submit for approval details of the shape and size of the gaskets he proposes to furnish. If required by the engineer, the contractor shall also submit test results showing the chemical and physical properties of the materials used in the manufacture of the gaskets.

Sec. 3.5—Fabrication of Reinforcement Cage

The steel reinforcement cage or cages shall be made of continuous or welded steel rods or wire wound in helical form, individual bars shaped and butt- or lap-welded into circular rings, or welded fabric shaped and butt- or lap-welded into cages, as approved by the purchaser. Each circumferential butt weld in the rods or bars shall be subjected to a test stress of 25,000 psi. before being assembled in the cage. When welded fabric is used, each welded splice or intersection shall develop a tensile strength not less than the minimum strength required for the reinforcement by the applicable specifications cited in Section 3–2.6. The circumferential rods, bars or fabric in the cage shall be accurately spaced and shall be rigidly assembled by means of longitudinal rods securely attached to them in approved manner. Each cage shall be fabricated and rigidly held in such a manner that the reinforcement will remain in proper position during the casting of the pipe. The minimum distance between the reinforcing steel and the surface of the pipe shall be $\frac{3}{4}$ in.

Sec. 3.6—Concrete for Pipe

3.6.1 *General.* The concrete may be placed by the centrifugal method, by the vertically cast method or by other approved methods.

3.6.2 *Proportioning.* The proportions of cement, fine aggregate, coarse aggregate and water used in concrete shall be subject to the approval of the engineer. The proportions shall be determined and controlled as the work proceeds, to obtain homogeneous, dense, workable, durable concrete of specified strength in the wall of the pipe and a minimum of defects in the surfaces of the pipe. The proportions shall be those which will give the best overall results with the particular materials and method of placing used for the work. A minimum of 7.0 bags of ce-

ment shall be used for each cubic yard of concrete. The water-cement ratio shall be such as to assure that the concrete will meet the strength requirements.

3.6.3 *Measurement of materials.* A barrel of cement shall be considered as 4 cu.ft. or 376 lb., and a bag of cement shall be considered as 1 cu.ft. or 94 lb. Cement in standard sacks need not be weighed, but bulk cement shall be weighed. Water for mixing shall be measured by volume or by weight. Concrete aggregates for each batch shall be measured separately by weighing. The proportions of aggregates shall be computed on the saturated and surface-dry basis and the water-cement ratio shall be exclusive of water within the aggregates and absorbed by them. The equivalent unit weights for both fine and coarse aggregates shall be determined in accordance with the "Standard Method of Test for Unit Weight of Aggregate" (A.S.T.M. C29), using a 1-cu.ft. cylindrical container. The equipment and devices for weighing and measuring shall at all times be accurate within 1 per cent.

3.6.4 *Mixing.* The mixing shall be thoroughly done by a mixer of approved type. Mixing time shall be at least three minutes. Transit mixing shall not be used except by written authorization and under specific requirements of the engineer.

3.6.5 *Standard test cylinders.* A set of at least four standard test cylinders shall be taken from each day's pour of the mixed concrete for pipe made by the centrifugal method, the vertically cast method or by other approved methods. Standard test cylinders shall be made and stored in conformance with the "Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field" (A.S.T.M. Designation C31). The curing of the test cylinders shall be in conformity with the curing of the pipe.

3.6.6 *Centrifugal test cylinders.* If the centrifugal method is used for making pipe, additional sets of four test cylinders of approved size and type shall be made by the centrifugal process at the beginning of the work and at intervals during the manufacture of the pipe. The number shall not exceed one set for each 400 lengths of pipe. Centrifugal cylinders shall be made by attaching to the spinning mold a test cylinder mold and placing the concrete within it by spinning at the same speed and for the same interval employed in the manufacture of the pipe. The concrete shall be spun in the centrifugal test molds in approximately 2-in. layers. The test cylinders shall be tested at the expense of the purchaser in an approved testing laboratory at 7, 14 and 28 days to establish and check ratios of strength of the two types of cylinders. Upon determination of this ratio, the strength of the concrete pipe shall be determined by application of the ratio of strengths obtained for the two types of test cylinders.

3.6.7 *Testing cylinders.* All test cylinders shall be tested by an approved testing laboratory at the expense of the purchaser, unless the manufacturer has approved testing facilities at the site of the work. In such event, tests may be made by the manufacturer in the presence of the engineer, or, if permitted by the engineer, certified test reports may be submitted by the manufacturer.

3.6.8 *Forms.* The forms shall be of steel made with butt joints throughout and with the interior surface smooth and true. All forms shall be sufficiently tight to prevent leakage of mortar; and they shall be stiff enough and so braced as to withstand, without deformation,

all operations incident to the pouring or spinning and setting of the concrete.

The forms shall be so constructed that the inner form (where pipe is vertically cast), outer forms, joint rings or end rings for forming the pipe joint and reinforcement shall be held in circular and concentric positions throughout the placing of the concrete; and so designed that the pipe can be stripped from the forms rapidly and without damage to the pipe surfaces. Forms shall be cleaned and oiled before each period of use.

3.6.9 *Strength of concrete.* Standard concrete cylinders shall attain a compressive strength of not less than 2,600 psi. in 7 days and 4,500 psi. in 28 days. Centrifugal test cylinders shall attain a compressive strength of not less than 3,500 psi. in 7 days and 6,000 psi. in 28 days. Pipe made from concrete which does not meet the strength tests will be subject to rejection.

3.6.10 *Placing concrete by centrifugal method.* The molds for forming the pipe shall be placed horizontally in a spinning machine. The method of placing concrete in the mold and the speed of rotation during placing shall be such as to prevent separation of concrete materials and the displacement of the steel reinforcement from its proper position and further, shall insure that the concrete will be evenly distributed and well compacted at the specified thickness throughout the length of the pipe. After the concrete has been deposited, the rotation shall be continued at a speed and for a length of time sufficient to provide the specified strength and sufficient compaction and bond to permit removal from the spinning machine without injury to the pipe. Excess water and laitance shall be removed from the interior surface of the pipe in an approved manner so that the surface shall be solid, straight and true. If necessary to provide a smooth surface, the interior shall be honed.

3.6.11 *Placing concrete by vertically cast method.* The transporting and placing of concrete shall be carried out by approved methods which will prevent the separation of concrete materials and the displacement of the steel from its proper position in the forms and the distortion of the forms. Approved methods of vibrating or rodding shall be used to compact the concrete in the forms to secure satisfactory surfaces of the pipe. The tops of the pipes shall be kept covered until the forms are removed. Forms shall not be removed until the concrete has set sufficiently to avoid spalling or damage to the pipe during the process of form removal.

3.6.12 *Other methods of placing the concrete.* If the contractor proposes to employ a method other than the centrifugal or vertically cast methods for placing the concrete within the mold, he shall submit for approval with his bid complete details of the method and equipment he proposes to use.

Sec. 3.7—Curing of Pipe

3.7.1 *General.* The pipe shall be cured by steam or by water unless otherwise specifically permitted. Steam shall be used for curing unless the temperature in the curing chamber is continuously above 50°F. Adequate space and facilities shall be provided for proper curing.

3.7.2 *Steam curing.* After the pipe has been cast, it shall be placed under cover for steam curing and when the concrete has hardened sufficiently, the pipe shall be kept in contact with moist steam at a temperature of at least 110°F. and not more than 150°F. for a period of at least 36 hours. Curing

by steam shall be continuous except during the period necessary to remove the forms or supporting rings. The forms shall not be removed until at least 6 hours after the beginning of curing. Water curing for at least 6 days, as specified below, may be used after forms are removed in lieu of steam curing.

3.7.3 *Water curing.* The pipe shall be kept moist by water spraying for a period of at least 36 hours. Following this minimum period, they may be "tipped" from their bases and removed to the storage yard where they shall be kept continuously moist by intermittent spraying for a period of at least 6 days.

Sec. 3.8—Testing of Pipe

3.8.1 *General.* Internal pressure and/or external loading tests of pipe at the manufacturer's yard will not be required unless they are specifically ordered by the purchaser, and such tests shall be at the purchaser's expense. The number of tests, type of tests and specific conditions of acceptance or rejection shall be as specified by the purchaser. Following are suggested procedures for hydrostatic pressure tests and crushing strength tests on fully cured and surface dry pipes:

3.8.2 *Hydrostatic pressure tests.* Hydrostatic pressure tests on pipe and joints may be made together by attaching two pipes together or a pipe and a standard joint section, or the tests may be made separately. The test section shall have suitable steel bulkheads attached to the ends and shall be filled with water and permitted to stand under a pressure of 10 psi. for a 2-hour period. The pressure shall be gradually increased until it reaches 120 per cent of the pressure for which the pipe is designed. It should be kept under the test pressure for at least 20 minutes and no cracks or measurable leakage should develop during the test period. Damp spots or water drops developing on the surface of the pipe should not be considered as leakage and cause for rejection. The joint should show no leakage at the test pressure.

3.8.3 *Bearing or crushing strength test.* This test should be in accordance with the 3-edge bearing test as described in A.S.T.M. Designation C76 for "Reinforced Concrete Culvert Pipe." Unless specifically required by the purchaser, the test should be limited to the loading required to produce the first 0.01-in. crack 1 ft. long, as described in that specification. The test should include the bell and spigot ends of the pipe and the loading block and bottom bearing strips should be shaped properly over the ends and provided with bearing caps of cement mortar. To avoid the necessity of applying loads in excess of the capacity of the loading machine, large pipe should be cut and tested in sections. The purchaser shall stipulate conditions as to loading and acceptance in accordance with external load for which the pipe is designed.

3.8.4 *Field testing.* Field tests on completed portions of the pipe line are not covered by these specifications for the manufacture of the pipe but should be included in specifications for pipe laying.

Section 4—Specials and Fittings

Sec. 3-4.1—General

The manufacturer shall furnish all fittings and special pieces required for closures, curves, bends, branches, manholes, air valves, blowoffs and connections to main-line valves and other pipes

shown on the contract drawings or ordered by the purchaser. Specials shall conform to the details furnished by the purchaser or—if required—to the details furnished by the manufacturer and approved by the purchaser. Either of two types shall be used:

Type A—specials of cut and welded steel-sheet cylinder of approved thickness, concrete or mortar lining and reinforced concrete or mortar exterior covering;

Type B—specials of cut and welded steel plate of approved thickness, with mortar coating on the interior and exterior.

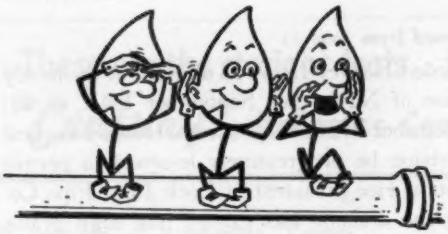
Sec. 4.2—Specials (Type A)

The steel sheet shall be cut, shaped and welded to form the properly shaped bend, tee, reducer or other special. The welds shall be inspected, and the completed cylinder shall be tested for tightness by an approved method, if specifically required by the purchaser. A cage or cages of steel reinforcement with approved cross-sectional areas shall be formed around the cylinder and openings. Longitudinal reinforcement sufficient for the additional stresses in the pipe walls shall be provided. The interior and exterior concrete or mortar shall be placed in an approved manner.

Sec. 4.3—Specials (Type B)

4.3.1 The steel plate for the fabricated steel plate specials shall be cut, shaped and welded so that the finished special shall have the required shape and interior dimensions. The deflection angle between adjacent courses of a bend shall be not greater than $22\frac{1}{2}$ deg. Adjacent courses shall be joined by butt welding. The minimum length of the courses shall be one-half the diameter of the pipe. The welds shall be inspected and the completed cylinder shall be tested for tightness by an approved method, if specifically required by the purchaser.

4.3.2 Wire-mesh reinforcing shall be applied to the interior and exterior surfaces of the fabricated special. It shall be 2×4 in. No. 13 gage welded wire fabric, held $\frac{3}{8}$ in. from the surfaces of the steel plate. The members on the 2-in. spacing shall extend circumferentially around the special with ends overlapped 4 in. and tied together. Longitudinal splices shall be staggered.



Percolation and Runoff

Modern civilization is waterborne! That's the story told in cartoon, editorial and front-page feature of the Louisville, Ky., *Times* of September 4, date of a main break that left most of Louisville without water for five hours of the morning after this year's long weekend. Fortunately, the five-hour drought began in the very wee hours of the morning, so though there were many tales of cooking and shaving with ice cubes and soda water, though hospitals had to shift over to emergency supplies and though industry was a little delayed in getting production lines going, there was no major discomfort or damage—just enough to make many Louisvillains appreciate the value of their water supply.

That's the story, too, of the August earthquake in Hawaii. The estimated million dollars of damage was virtually forgotten in the worry over water supply when it was discovered that the quake had destroyed more than 200 of the wooden water tanks which supply individual families along the hard-hit Kona coast. With two months of normal drought ahead, coffee farmers and cattle ranchers of the area were as worried about their business as their personal requirements. And supplies had to be hauled in from Hilo, a hundred miles away.

With more and more people every month discovering just how vital water is, we wonder why so few realize it. Seems to go in one end and out the other.

A nickel for a penny will be the story soon if the copper shortage gets any worse. In early September, NPA was standing on its head to get dealers and generators of copper and copper-base alloy scrap to speed the flow of this vital material to custom smelters, ingot makers, brass mills, brass and bronze foundries and other users. And since your allotments under CMP are at stake, anything you can do to help the cause will be strictly helping yourself. It hasn't gotten to the stage yet of buying pennies for nickels, but we have been urged to break up our penny collections to reduce the need for new coins. As a matter of fact, with prices the way they are, who would miss pennies, anyway, if they were all called in?

(Continued on page 2)

(Continued from page 1)

Gerald E. Arnold has succeeded Harvey Howe as director of the newly created Water Resources Division of NPA (see September P&R, p. 4). The change was effected on September 18 in response to Howe's request that his connections with the division be progressively lessened to permit him to resume his duties as assistant vice president of Lock Joint Pipe Co.

Howe's work in organizing the division has earned him high praise throughout the water works field. A.W.W.A. Secretary Harry E. Jordan, in his capacity as secretary of the Water, Sewage and Industrial Wastes Joint Committee on Critical Materials, stated:

> As an individual who has watched the development of the NPA Water Resources Division and participated to some extent in the task of getting it established, I want to pay tribute to Harvey Howe for the extraordinarily competent fashion in which he has carried on this work. The interferences with the orderly development of the Water Resources Division have been many and have derived from surprising sources. Howe's patience and tact have borne fruit in the establishment of the competent group that is now working in the interest of U.S. water resources.

The division's new director, Gerald E. Arnold, comes to that post from the San Diego, Calif., Water Dept., of which he was also director. During World War II he left his position with the San Francisco Water Dept. to become western field representative of the Office of Civilian Defense. Later he joined the staff of the Water Division of the Office of War Utilities. He came to San Diego after the war as assistant to the city manager, and then moved on to the Water Dept.

A snake in the glass was almost the story at a home in the town of New Castle, N.Y., the other day, but fortunately the service pipe performed a real service in putting a stop to the thing. And when water superintendent Charles Dedde, responding to the complaint of no pressure, pulled a 30-in. water snake out of the line he was hard put to explain. We won't comment on the possibility that it entered the system when new mains were being laid in the neighborhood, but we will shudder at the thought that some good bourbon might have been in the glass. Worse yet, it might have been the second drink!

Watt wot what water was, but until a couple years ago very few had given him credit for much more than pottering around with it hot to make steam to make his steam engine operate. That our boy Jimmy was really first to put two H's and an O together was recently revealed in the discovery of a letter written by British scientist Joseph Priestley way back in 1783. Information contained in this letter was credited with resolving a century-old controversy concerning the discoverer of the composition of water. Why did they think it was named after Jim anyway?

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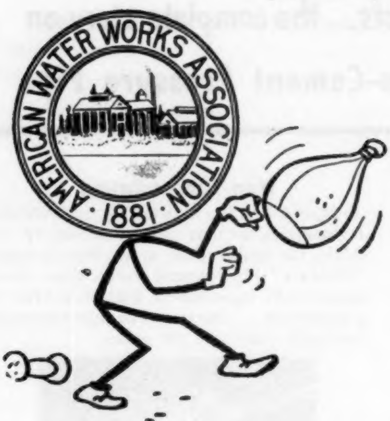
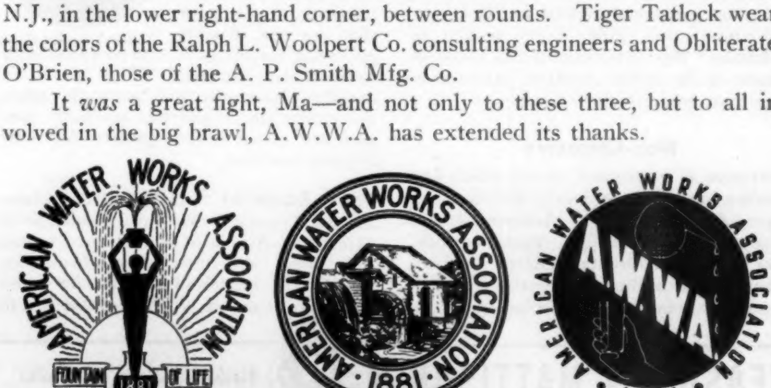


The Winner and Still Champion, though everyone thought he had lost his punch, is the old walrus—oops, seal we mean—himself. And inasmuch as he has successfully defended his title against 65 contenders in the five months of A.W.W.A.'s seal contest, we're content now to leave him be. Getting older, ourself, we find it easier to make peace with tradition anyhow. Thus approval of the seal has our seal of approval!

But don't think the fights were soft touches. Every one of the 65 challengers was in there punching all the time, and it's pretty clear that it was only the old timer's experience that pulled him through. Strangely enough, though, he seemed to get stronger as the fights went on, so that when the 40 judges were polled at the end, it wasn't even close. Of course, it's tradition, too, that a championship should be won by a knockout—or, at least, almost.

Strong man among the contenders was Jolting Jim Pritchard of Ottawa, Ont., shown below in the left-hand corner, wearing black trunks. Jim, who is a Jr. Engr. at the Ottawa Water Works Dept., put up such a spirited battle against the old slugger that the judges awarded him a "logical contender" rating and a special purse of $50—half the jackpot. Tied for "leading boxer" ratings behind the Canadian Clipper were two U.S. ring kings: M. W. (More Wheaties!) Tatlock of Dayton, Ohio, pictured in the middle below; and Brutal Hubert O'Brien of East Orange, N.J., in the lower right-hand corner, between rounds. Tiger Tatlock wears the colors of the Ralph L. Woolpert Co. consulting engineers and Obliterater O'Brien, those of the A. P. Smith Mfg. Co.

It *was* a great fight, Ma—and not only to these three, but to all involved in the big brawl, A.W.W.A. has extended its thanks.



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Needed for national defense are the following items in short supply, in order of increasing importance:

1. **Money**—to be invested in defense bonds through Payroll Savings Plans. The Savings Bond Div., U.S. Treasury Dept., Suite 700, Washington Bldg., Washington, D.C., as well as state directors, can furnish application blanks, posters, envelope stuffers, personal assistance—everything but the cash.

2. **Iron and steel scrap**—a half ton is needed for every ton of steel produced, and inventories are down to subsistence levels or below. Route through established scrap dealers.

3. **Copper** and copper-base alloy scrap (see p. 1 for details).

4. **Blood plasma**—military supplies are hard pressed to meet the demands of the war in Korea, and additional donations are urgently required. See your local Red Cross office for arrangements.

5. **Lives**—the National Safety Council reports that the one-millionth will have been taken by traffic accidents by the end of this year, unless public attention is awakened to postpone it. One million dead is a toll no nation can afford. Are safety checks made regularly of brakes, tires, horns, steering gear and visibility on water utility vehicles? Are any manned by accident-prone drivers?

Rampant mental fluorosis is almost sure to have attacked a large number of the residents of Westchester County, New York, by now. At any rate, with the announcement that New Rochelle had installed fluoride feeding equipment and that a number of other communities were contemplating the action, sensitive Westchesterites began suspecting their taps. It wasn't long before complaints of strong fluoride tastes began to plague the County Health Commissioner and staining of enamel spread quickly from bathroom to mouth. And all this happened long before an ounce of fluoride had been added to any Westchester supply. Consider the calamity now, then, when one of the communities may already have started fluoridation. Or perhaps they're just beating their gums by now.

The Greeks had a word for it, and in Delphos, Ohio, they undoubtedly did too—though perhaps more vernacular than oracular. At any rate, the situation recently reported to the modern Delphic council was almost beyond words—involving many of the city's pillars in pilfering. It was water, of course, that undermined the pillars. What else could cause them to go underground as they did to bypass the city's curbside meters, "thus," said the report, "eliminating any charge." The council's solution was authorization of an additional employee to install, repair and inspect water lines and meters; and, if he doesn't earn his keep, Delphians will probably be an unwashed and thirsty lot.

(*Continued on page 8*)

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Use of a membrane filter for bacterial analysis of water may have "an importance in bacteriology comparable to Koch's use of solid culture media," according to Surgeon General Leonard A. Scheele. The occasion for the statement was the completion of preliminary studies of the technique at the U.S. Public Health Service's Environmental Health Center at Cincinnati, Ohio. Not only does the use of the filter reduce the test period to a matter of hours, but it makes possible the use of much larger samples than have heretofore been taken, by its portability extends the range of testing to rural and other areas which previously had to rely upon ice-packed sample shipment, and permits separate incubation of individual bacteria into discrete colonies. For example, it is possible to isolate and identify *S. typhosa* "with an ease that contrasts strikingly with the difficulty experienced with analysis by other methods," according to Mark D. Hollis, assistant surgeon general and chief sanitary engineer. Much work remains to be done, however, to develop the full range of practical applications of the filter technique.

Jack R. Barnes has joined the staff of Walter N. White and William F. Guyton, which will now be known as White, Guyton and Barnes.

(Continued on page 10)

(*Continued from page 8*)

John E. Bacon died on August 27, just over a month after his retirement as head of the Bureau of Chemistry in the New Jersey State Health Dept. He had been with the department for 39 years.

Claude Burdick, plant supervisor of the Flint, Mich., Water Dept. died on July 27 at the age of 58. He had served the department since 1920, first as assistant chemist and then for nearly a quarter of a century as chief chemist and purification supervisor. In 1947 he was appointed to the post he held at the time of his sudden death.

After majoring in chemistry at Kalamazoo College and the University of Michigan, he worked for a Flint construction company for a time before joining the Water Dept. staff. His last great project had been the planning of Flint's new filtration plant, the necessary priorities for which had been received from NPA on the day of his funeral.

Sydney W. Kitson, manager of the Public Works Div. of Worthington Pump & Machinery Corp., died on August 28 in Boston, Mass., after having been hospitalized there. He was 53, and associated with the Worthington organization for the past 30 years.

William R. Luby, former public works commissioner of Troy, N.Y., and chief engineer of the Tory Water Bureau, died on August 3 after a long illness, at the age of 57. He had resigned as commissioner earlier in the year because of a heart ailment.

Erie W. Sherman, president of Sherman Machine & Iron Works died on August 12 after a heart attack. In ill health for the three months preceding, he was 56 years old. A prominent Oklahoma City Contractor, he was president and organizer of the Texas and Oklahoma branch of the American General Contractors Assn., and was responsible for a movement to improve standards of workmanship and business conduct. He was also active in the affairs of the Southwest Section of A.W.W.A., and spearheaded a recent drive the Section was conducting to increase A.W.W.A. membership.

A molded ring packing has been developed by Johns-Manville and is known as "Uneepac." Furnished in various compositions to suit different service requirements, the packing was intended to permit redesign of equipment with smaller space allowance for stuffing boxes, as the packing is said to offer maximum sealing efficiency with minimum depth. Each ring centers itself automatically on preceding rings, and follower or header rings are not required. It is available for shafts of $\frac{5}{8}$ in. diameter and larger.

(*Continued on page 12*)

For large valves and frequently used valves, operating costs often are reduced and efficiency increased by remote control. In emergencies, quick operation of distant valves may be an extremely vital matter.

M & H Valves are furnished both for manual or remote control. M & H Hydraulic Valves have either Cast Iron Brass-Lined or Skeleton Type Brass cylinders, and are furnished with or without square bottom. Also electric motor operators can be adapted to M & H Valves.

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(*Continued from page 10*)

Sessions on CMP records and accounting, depreciation rates for water and electric plants, and the impact of water-using electrical appliances on water and electric distribution systems are included in the program for the 19th Annual Conference of the California Municipal Utilities Assn., to be held in Oakland November 13–16.

What Price Water when the tax alone amounts to $1,000,000 per mil.gal.? That's the tariff you pay to import good Scotch water in good Scotch, and, as 14 per cent of any good Scotch is water, you can figure your own water bill by adding to the calculated cost a 50 per cent mark-up. Of course, someone has already thought of importing the 100-proof whisky and watering it down to 86 proof with some good untaxed American water, but the resulting selling price of his Scotch is so low that "it can't be any good"—thus, you won't find it among the best sellers. Besides, say the Scotch, even if good Amerrrrican water were as good as good Scotch water for Scotch, it would be under the tremendous disadvantage of remaining unmarried (marrying being the process of getting together with whisky in a barrel and emerging more flavorful). Since we believe in both matrimony and good Scotch and since we're not at all interested in tariff protection against the competition of Scotch water, we're all in favor of cutting the price by cutting out the tax on the stuff used in cutting the whisky. And if even then we can't afford the Scotch, maybe we can swing a deal for a little married water.

Getting closer to reality, though, we might point out that the water we drink in beer is also married. And where, indeed, could prouder in-laws be found than the makers of Fox Head beer, who actually boast of a product "brewed with Waukesha water." Let us be the ones to remember Poppa A. P. Kuranz who gave them reason to be proud. And, for the moment, let us get our minds off the brood brewed.

(*Continued on page 14*)

(*Continued from page 12*)

Now you can be a two-dollar-a-year man! All you need is extra or idle sets of the JOURNAL for any or all the years form 1935 through 1950 and facilities for crating and freighting them on an all-expenses-paid trip to Sweden. In addition to the "expenses," for each year's issues you make available there is a small fortune forthcoming—if, of course, you bet it on the right horse. Fact of the matter is a new A.W.W.A. member-engineer in Sweden is opening his own consulting office and wants to start his library right, but the Swedish government authorization of dollar expenditures is hard to obtain unless there's a real bargain on tap. We think the JOURNAL's a bargain at any price, but don't know how to say that in Swedish. So if you want to be twice as good as guys like Wilson, Johnston and Di Salle and an exporter to boot, write Bucks Two, Journal A.W.W.A.

Jens Duus has been appointed factory manager of the Buffalo Meter Co., succeeding Walter Boals upon the latter's resignation because of ill health. Duus was factory manager for Phoenix Meter Co. from 1925 to 1941, when he joined the National Meter Div. of Rockwell Mfg. Co., leaving that organization earlier this year.

(*Continued on page 16*)

(Continued from page 14)

Sniffers, Snoopers, Classmasters, Cutie-Pies and Ferrets are now all for sale just across the street from A.W.W.A. headquarters. Even if you want a "Civion" or a "Zeuto," we can get it for you retail from one of the former atom bomb scientists who started and now staff the Radiac Company, first retail shop for atomic instruments in the world. Counting among its customers prospectors, physicians, laboratory technicians, teachers, civil defense workers, hobbyists, engineers, and just plain water works men, Radiac peddles refinements of the old bulky Geiger Counter and new, more sensitive scintillometers. To translate the atomic, we might explain that the "Sniffer," "Supersniffer," "Ferret" and "Snooper" are prospectors' tools; the Classmaster is for the educator; and the "Civion" for civil defense workers. About the "Cutie-Pie," you can draw your own conclusions, but we wouldn't be a bit surprised if the unidentified "Zeuto" weren't reserved strictly for spies. What price progress?

"Periodicals of Interest to Public Health Workers," a list of 457 publications received regularly at the National Health Library, is being offered as a bibliographical guide at a cost of 50¢ per copy from National Health Council, 1790 Broadway, New York 19, N.Y.

Wentworth Smith has been appointed general sales manager of Neptune Meter Co. He had been assistant general sales manager for the company for the past year, after having performed special market studies. Previously he had been with the sales staff of Safety Car Heating & Lighting Co.

Walter H. Brown, sales engineer with the Standard and Engineered Products Dept., Builders-Providence, Inc., has been transferred to the Projects Dept., where he will specialize in equipment applications for waste treatment.

Saucerer's Apprentice first class may not sound much like an Army rank, but just you wait and see. Only the other day the Army announced that it was testing 24-in. inflated rubber "saucers" for dropping supplies of water, gasoline and other liquids to troops in the field. In letting these supplies fly from the plane, saucerers attach no parachutes, for, upon impact with the ground, the containers do a two-way stretch to about twice normal size, bounce and then settle on the ground without bursting.

Under no circumstances are these saucers to be confused with those of the Air Force, which remain uncaptured though observed doing 900 mph. over New Jersey by jetmen hobbling along at 450. Saucererless as far as we know, these AF whoooosh are apparently also useless if not worse. Not only can you not drink out of them, they drive you to drink.

(Continued on page 18)

(Continued from page 16)

Speaking of words, though, our friends on the other side of everything seem to be a little confused. When the chemical division of the U.S.S.R. Academy of Sciences attacked the famed resonance theory of chemical bonds developed by Prof. Linus Pauling of our California Inst. of Technology as "pseudo-scientific," "vicious" and an example of "world outlooks hostile to the Marxist view," we must assume that one of those political chemists got his "bonds" mixed up. Not that it will now help the four "censured" Soviet chemists, but we feel we owe it to their memory to point out that Prof. Pauling's laboratory is nowhere near Wall Street.

Of course, when Voprosy Filosofii starts making cracks about our Machistic theoreticoperceptional settings, we're just as comprehending as must have been Groucho's bother Karl when he pre-established all the hypotheses to be developed from the physical theory of quantum mechanics. Oh well, Groucho never made much sense either.

"Liquid of life" is the billing given water in General Electric's new film, "Pipeline to the Clouds," which you'll be seeing one of these days at your local section meeting. Both the film and the manual, "Good Water and Plenty of It," which accompanies it will be available to water works men for use in selling water supply and new water supply projects to their public. But, if the sendoff it received in New York last September 11 is any indication, you'll be hearing about this "More Power to America" program from other sources, and often too. Both Surgeon General Scheele and our own Veep Charlie Capen were at the GE's Hotel Barclay "Press Premiere" to wish it very well. And we understand that the wellness is going to be guaranteed by a lot of GE energy and enthusiasm.

Just in case you are able to insulate yourself against this campaign and still would be interested in its object, you can borrow the film through any GE branch office and obtain a copy of the manual by writing direct to the Advertising & Sales Promotion Dept. at Schenectady, N.Y.

(Continued on page 20)

(*Continued from page 18*)

Publication of the *1951 Code for Pressure Piping* has been announced by the American Society of Mechanical Engineers, 29 W. 39th St., New York 18, N.Y. The book is a revision of the 1942 code and contains data on power piping systems and piping for gas and air, oil, heating and refrigeration, with tables of allowable stresses and information on supports and braces, welding and materials specifications.

Also just issued is a *Ten-Year Index to A.S.M.E. Technical Papers* which covers the *A.S.M.E. Transactions, Mechanical Engineering* and the *Journal of Applied Mechanics* for the decade 1940–1949.

Earnest Boyce has completed a public health mission in Western Germany and has returned to the University of Michigan, where he is chairman of the Dept. of Civil Engineering. As the only sanitary engineer in a team composed of seven public health workers and doctors, he spent two months meeting with German officials and informally discussing common public health problems. The trip was sponsored by the Unitarian Service Committee and received the blessing of the U.S. State Dept. Among those he met in the course of the trip was Imhoff, originator of the well known sewage treatment unit.

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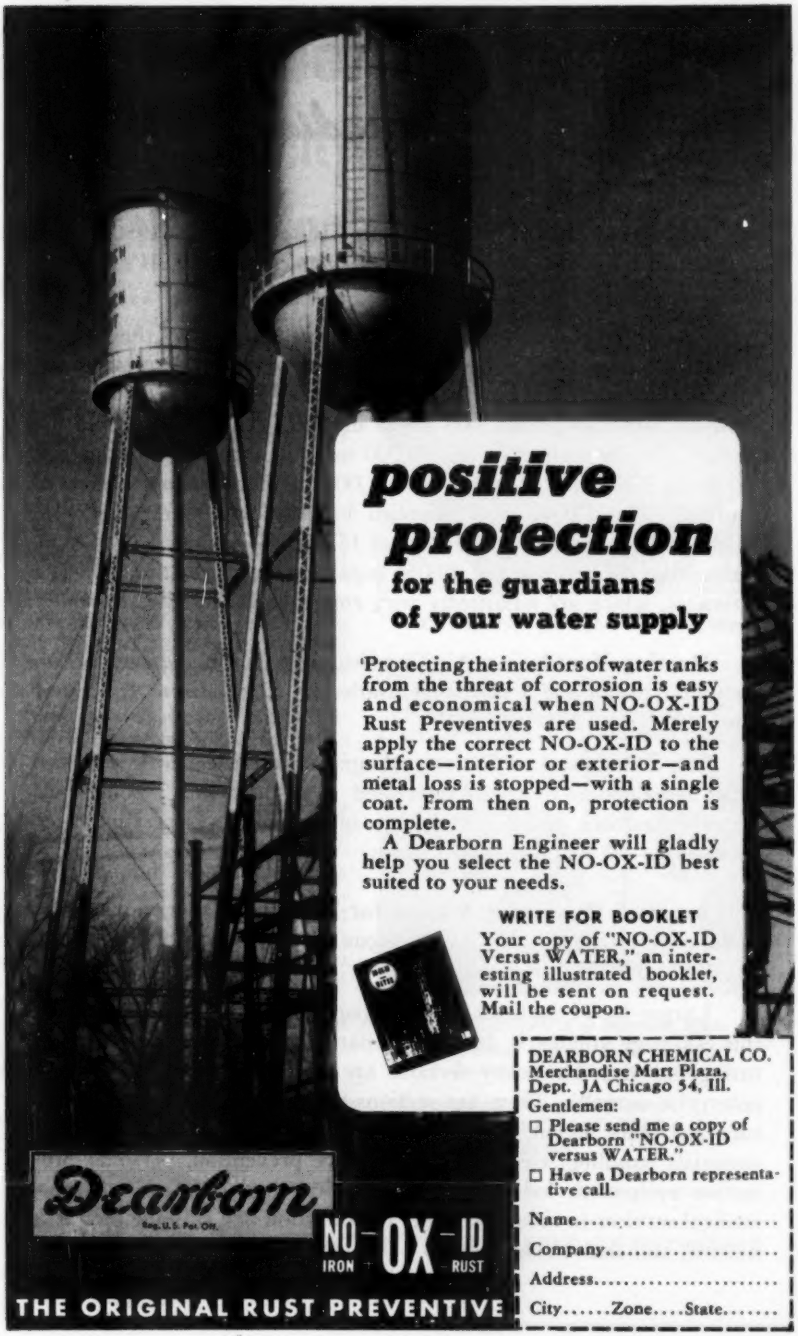

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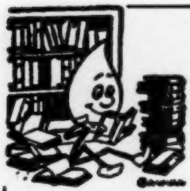

The Reading Meter

Estimated Use of Water in the United States—1950. *Kenneth A. MacKichan. Circular 115, Geological Survey, Washington 25, D.C. (1951) free*

Among the valuable statistical estimates supplied by this slender booklet are those which give the total use of water for domestic, commercial, industrial and agricultural use during 1950 as 173,600 mgd., with an additional 1,100,000 mgd. used to generate hydroelectric power. Of the former figure, 79,000 mgd. is allocated to irrigation, 3,600 mgd. to rural supplies and 77,000 mgd. to private industrial sources. The 13,640 mgd. supplied by municipal water works to 93,500,000 consumers—an average of 145 gpcd.—includes 3,584 mgd. taken from the ground and 10,056 mgd. from surface sources. The estimates, which are admittedly very rough, include reuse.

Heating Ventilating Air Conditioning Guide. *American Society of Heating and Ventilating Engineers, 51 Madison Ave., New York 10, N.Y. (1951) $7.50*

The 29th annual edition of a recognized reference work will need little introduction to those interested in its contents. Some new material has been added. The scope of the volume is best indicated by its size—50 chapters, 1,476 pages.

Accident Prevention Manual for Industrial Operations. *National Safety Council, 425 N. Michigan Ave., Chicago, 11, Ill. (2nd ed., 1951) $18*

Larger by 11 sections and 256 pages than the edition of 1947, this 800-page volume is devoted primarily to safety in the manufacturing industry, but many sections are applicable to other types of enterprise as well. There are sections dealing with permanent structure and plant layout, maintenance and maintenance crews, boilers, materials handling, electrical hazards, fire prevention, personal protective equipment, industrial health engineering, industrial poisons, medical services in industry, safety organization and training, accident records, and analysis and costs.

(Continued on page 86)

Professional Services

Membership Changes

NEW MEMBERS

Applications received August 1 to August 31, 1951

Allen, John W., Contractor, Christian & Allen, Ltd., Ladner, B. C. (July '51) *M*

Andriotis, Theodore Michael, Asst. Engr., Design Office, Washington Suburban San. Com., Hyattsville, Md. (July '51) *MPR*

Baird, Gilbert O., Water Supt., Taft, Tex. (July '51) *M*

Beatty, Dr. Norman M., Memorial Hospital, Ray D. Gangwer, Chief Engr., Box 473, Westville, Ind. (Corp. M. July '51) *MPR*

Bonine, E. D., *see* Lyons (Neb.) Munic. Water Plant

Bonnell, A. R., Engr., Municipality of St. John, Box 38, Fairville, N.B. (July '51)

Booz, F. B., Dist. Mgr., Horton Steel Works Ltd., 1414 University Tower Bldg., Montreal 2, Que. (July '51)

Bromley, George, Cons. Engr., Kearns & Bromley, Box 280, Wolfville, N.S. (July '51)

Brown, Charles Yancey, Pres. & Gen. Mgr., Washington Water & Light Co., Box 428, Sacramento, Calif. (July '51) *M*

Bryan, Stanley E., Clerk-Treas. & Acting City Engr., Bayard, N.M. (July '51) *M*

Buzzoni, Anthony Tarcisius, San. Engr., Nussbaumer Clarke & Velzy, 52 Vanderbilt Ave., New York, N.Y. (July '51) *P*

Cotter, Chester, Chairman, Board of Public Works, City Hall, North Kansas City, Mo. (July '51) *M*

DeLano, Reuben G., City Supt., St. Clair, Mich. (July '51) *M*

Evans, W. F., *see* Franklin (N.J.) Water Co., The

Everall, R. S., *see* Flin Flon (Man.)

Fetterly, A. D., Vice-Pres., S. T. E. Fetterly & Son, Ltd., 75 Upper Water St., Halifax, N.S. (July '51)

Fetterly, S. T. E., Pres., S. T. E. Fetterly & Son, Ltd., 75 Upper Water St., Halifax, N.S. (July '51)

Fetterly, W. E., Secy., S. T. E. Fetterly & Son, Ltd., 75 Upper Water St., Halifax, N.S. (July '51)

Finn, Richard H., Supt. of Water Dept., Board of Public Affairs, Green Springs, Ohio (July '51) *M*

Flin Flon, Town of, R. S. Everall, Town Engr., Flin Flon, Man. (Corp. M. July '51)

Fournier, Gerald, Water & Sewer Supt., Edmundston, N.B. (July '51)

Franklin Water Co., The, W. F. Evans, Supt., Franklin, N.J. (Corp. M. Apr. '51) *MP*

Gangwer, Ray D., *see* Beatty, Dr. Norman M., Memorial Hospital

Goldberg, William, Civ. Engr. in charge of Distr. & Maint., Dept. of Water Supply, Gas & Electricity, 309 Borough Hall, Staten Island 1, N.Y. (July '51) *MPR*

Greene, Gordon Z., Gordon Z. Greene Co., 2335 E. 8th St., Los Angeles, Calif. (July '51) *MPR*

Ham, J. Earl, *see* Sylacauga (Ala.)

Hawksley, Ray W., Chem. Engr., Ray W. Hawksley Co., 320 Market St., San Francisco 11, Calif. (July '51)

Hazlip, Samuel William, III, Civ. Engr., Design Section, East Baton Rouge City-Parish Dept. of Public Works, Baton Rouge, La. (July '51) *MPR*

Heinrikson, J. J., Salesman, 406 Merchandise Mart, 2201 Grand Ave., Kansas City, Mo. (July '51) *P*

Hill, Frederick George, Little Orchard, St. Catherine's Rd., Haylina Island, Hampshire, England (July '51) *MPR*

Huff, M. F., Sales Engr., Rockwell Mfg. Co., 413 Bona Allen Bldg., Atlanta, Ga., (July '51)

(*Continued on page 32*)

(*Continued from page 30*)

Hunt, Leigh B., Supt. of Water Constr., Water Works, Fremont, Ohio (July '51) *M*

Larson, Bernt O., Assoc. Prof., College of Eng., Univ. of Illinois, Urbana, Ill. (July '51) *R*

Lewis, Robert Milton, Asst. Engr., National Board of Fire Underwriters, 85 John St., New York 38, N.Y. (July '51) *M*

Lieding, Roger W., Chemist-Supt., Filter Plant, Board of Water Comrs., City Hall, Sheboygan, Wis. (July '51) *P*

Lindman, Winton, Owner, Culligan Soft Water Service, Ortonville, Minn. (July '51) *PR*

Lone Star Steel Co., Walter T. Moreland, Vice-Pres., 4501 W. Mockingbird Lane, Box 8087, Dallas, Tex. (Assoc. M. July '51)

Lyons Munic. Water Plant, E. D. Bonine, Supt., Lyons, Neb. (Corp. M. July '51) *MP*

MacIntosh, A. J., Sales Mgr., Concrete Pipe Div., L. E. Shaw, Ltd., 74 Bedford Row, Halifax, N.S. (July '51)

MacLure, James H., Mgr., Gill & Co., Ltd., 51 Water St., St. John, N.B. (July '51)

Marcano-Coello, Andres, Design Engr., Instituto Nacional de Obras Sanitarias, Edif. Las Mercedes, Caracas, Venezuela (July '51) *MPR*

McCandless, Charles Sprague, Cons. Civ. Engr., Box 845, Menlo Park, Calif. (July '51) *PR*

McGaughy, John B., Assocs., James A. Rives, Civ. & San. Engr., 21st St. at Llewellyn Ave., Norfolk, Va. (Corp. M. July '51) *MP*

McLellan, J. C., Accountant, Water Dept., Sydney, N.S. (July '51)

McNeill, Howard H., Mgr. & Pres., Terra Bella Irrigation Dist., Terra Bella, Calif. (July '51) *M*

Moon, Gerald R., Water Treatment Technician, Blackford Window Glass Co., Vincennes, Ind. (July '51) *P*

Moreland, Walter T., *see* Lone Star Steel Co.

Myers, Phillip Jacob, Sales Repr., Viking Supply Corp., 703 Standard Life Bldg., Jackson, Miss. (July '51) *M*

New London Light & Water Utility, L. K. Thomas, Supt., New London, Wis. (Corp. M. July '51)

Nichols, Paul Lewis, Sr. Civ. Engr., Eng. Dept., East Bay Munic. Utility Dist., 2127 Adeline St., Oakland 7, Calif. (July '51) *MPR*

Ott, Rupert C., Jr., Repr., Neptune Meter Co., 3114—13th St., Columbus, Neb. (July '51)

Paduano, Dominick F., Comr., Water Supply, Gas & Electricity, Municipal Bldg., New York 7, N.Y. (July '51)

Pearson, Dudley Charles, Engr.-Mgr., Lindmore Irrigation Dist., Box 995, Lindsay, Calif. (July '51) *MPR*

Plummer, John Donnelly, San. Engr., State Board of Health, Box 210, Jacksonville, Fla. (July '51) *MP*

Poor, Raymond S., Asst. Chief of Operations Branch, Washington Aqueduct, Corps of Engr., 1st & Douglas Sts., N.W., Washington, D.C. (July '51) *M*

Poston, Richard Leland, Surveyor, Water Dept., 215 W. Broadway, Long Beach, Calif. (July '51) *M*

Ramsberg, T. H., *see* Westbrook (Minn.)

Rives, James A., *see* McGaughy, John B., Assocs.

Ronson, George A., Secy., Public Utilities Com., Parkhill, Ont. (July '51)

Schomaker, William P., Sales Estimator, The Permutit Co., 330 W. 42nd St., New York 18, N.Y. (July '51) *P*

Smolak, George, Section Head, Transite Pipe, Johns-Manville Research Center, Manville, N.J. (July '51) *M*

South Farmingdale Water Dist., David Welsh, Secy., Linden St., South Farmingdale, N.Y. (Mun. Sv. Sub. July '51) *MP*

Stahl, Earl F., Sales Repr., Hersey Meter Mfg. Co., 1364 Arcadi St., St. Paul, Minn. (July '51)

Sylacauga, City of, J. Earl Ham, Supt., Water Dept., Sylacauga, Ala. (Mun. Sv. Sub. July '51)

Talladega Light & Water Com., W. Florey Tucker, Supt. of Water, City Hall, Talladega, Ala. (Mun. Sv. Sub. July '51) *M*

Thomas, L. K., *see* New London (Wis.) Light & Water Utility

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Towers, John William, Project Engr., Rader Eng. Co., 1615 DuPont Bldg., Miami, Fla. (July '51) *MPR*

Tucker, W. Florey, *see* Talladega (Ala.) Light & Water Com.

Van Allen, W. J., Owner & Operator, Culligan Soft Water Service, 122 Strafford St., Plymouth, Wis. (July '51) *PR*

Voorheis, Dewitt S., R. R. 1, Upper Sandusky, Ohio (July '51) *MPR*

Wagner, Victor G., San. Engr., State Board of Health, 1700 N. Harrison St., Fort Wayne, Ind. (July '51) *P*

Walborn, Herbert L., Mgr., Muhlenberg Township Authority, 431 Washington St., Reading, Pa. (July '51) *M*

Welsh, David, *see* South Farmingdale (N.Y.) Water Dist.

Westbrook, Town of, T. H. Ramsberg, Supt., Water & Light Dept., Westbrook, Minn. (Mun. Sv. Sub. July '51) *MP*

Wilkes, George J., Dist. Mgr., S. Morgan Smith Co., York, Pa. (July '51) *MPR*

LOSSES

Deaths

Kitson, Sydney W., Mgr., Public Works Div., Worthington Pump & Machinery Corp., Harrison, N.J. (July '45) *R*

Strockbine, Walter, Phiimont Ave. & Sterner Rd., R.F.D. No. 3, Langhorne, Pa. (June '27) *P*

CHANGES IN ADDRESS

Changes received between August 5 and September 5, 1951

Adams, John M., 1226—3rd Ave., W., Seattle 99, Wash. (Apr. '40) *MP*

Aultman, William W., Asst. Director, Dept. of Water & Sewers, Box 316 Coconut Grove Station, Miami 33, Fla. (Jan. '36) *P*

Barton, Harry, Box 468, West Chester, Pa. (Dec. '28)

Bates, R. W., Water Bureau Supervisor, Public Service Dept., Box 631, Burbank, Calif. (Oct. '37) *MR*

Bengel, William C., Designing Engr., Brown & Root Constr. Co., 707 W. French Ave., Temple, Tex. (Jan. '50) *MPR*

Bird-Archer Co., Ltd., E. L. Ruggles, Asst. Gen. Mgr., Cobourg, Ont. (Assoc. M. Oct. '37)

Birmingham Water Works Board, W. H. H. Putnam, Gen. Mgr., 2114—1st Ave., N., Birmingham 3, Ala. (Corp. M. July '47) *M*

Black, Ralph J., Asst. San. Engr., State Dept. of Public Health, 2400 McKinley Ave., Berkeley, Calif. (Apr. '51) *P*

Blais, Marcel, St. Germain de Grantham, Drummond, Que. (Oct. '49)

Boen, Doyle F., Gen. Mgr. & Chief Engr., Eastern Munic. Water Dist., Box 365, Hemet, Calif. (Oct. '48)

Bowen, Edward R., Cons. Engr., 475 Huntington Dr., San Marino 9, Calif. (July '36) *MR*

Bowman, James W., Civ. Engr., 374 Bob-O-Link Dr., Lexington, Ky. (Jan. '49)

Burbank Public Service Dept., J. H. McCambridge, Gen. Mgr., Box 631, Burbank, Calif. (Corp. M. June '27) *MR*

Calvet, Carlos M., *see* Marianao y Regla, Acueductos de,

Carman Sterne Maley Corp., Alexander B. Maley, Pres., 3604 S. Morgan St., Chicago 9, Ill. (Assoc. M. Jan. '50) *P*

Carter, Jay B., J. M. Montgomery & Co., Inc., 900 S. Robertson Ave., Los Angeles, Calif. (Jan. '49) *MPR*

Clark, Everett L., Cons. Engr., 215 W. 7th St., Los Angeles 14, Calif. (Oct. '39) *MPR*

Collins, Lindsay M., 722 Coleman Pl., Westfield, N.J. (Jan. '50)

Conkling, Harold, Cons. Engr., 448 S. Hill St., Los Angeles 13, Calif. (Oct. '39) *R*

Cook, Will W., Sales Engr., Proportioneers, Inc., Route 2, Box 361, Kirkland, Wash. (Apr. '38) *P*

Davis, Charles N., Asst. Supt., Constr. & Distr., 651—14th St., N.W., Atlanta, Ga. (Oct. '43) *M*

Dearborn Chemical Co., J. G. Surchek, Asst. Mgr. NO-OX-ID Sales, Merchandise Mart Plaza, Chicago 54, Ill. (Assoc. M. June '27)

Ewbank, Norman M., Jr., 1325 Stanton Ave., Whiting, Ind. (Oct. '49) *P*

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Farr, Leo Grant, Jr., 3307 St. Mathews Dr., Sacramento 15, Calif. (Apr. '48) *P*

Feagan, George H., 5915 Reiger St., Dallas 14, Tex. (Jan. '48)

Fenn, N. Frederick, Gen. Mgr., Suffolk County Water Authority, Bay Shore, N.Y. (Nov. '27) *M*

Fiesler, Frederick A., 1594 W. Hunt St., Decatur, Ill. (Jan. '44) *MP*

Fish, J. A., *see* Niagara Falls (N.Y.) Dept. of Water

Fulmer, Leu Relle, Jr., Sales Engr., R. D. Wood Co., Route 8, Box 242B, Little Rock, Ark. (July '50)

Gahr, William N., Director, Div. of San., State Dept. of Public Health, 790 Jasmine St., Denver 7, Colo. (Jan. '46) *P*

Geisler, P. W., 321 Lincoln Ave., Ridgewood, N.J. (Apr. '37)

Gleason, George B., Supervising Hydr. Engr., State Div. of Water Resources, 961 La Sierra Dr., Sacramento, Calif. (Jan. '49)

Gray, E. W., 125 S. Main St., Fairport, N.Y. (Apr. '44) *P*

Greer, H. C., Neptune Meters Ltd., 1430 Lakeshore Rd., Toronto 14, Ont. (Jan. '51)

Hostrup, Christian F., 543—9th St., Santa Monica, Calif. (Feb. '30) *MPR*

Kilby, H. S., Public Service Co. of Oklahoma, Box 201, Tulsa, Okla. (Jan. '47) *M*

King, Leslie R., 3118 Aloma, Wichita, Kan. (Oct. '46)

Kittrell, Francis W., 4600 Meadow Court, Knoxville, Tenn. (July '35)

Lalonde, J. A., Cons. Engr., 958 Dunlop, Montreal, Que. (Apr. '47)

Lawrence, Walter Byron, Project, Engr., Cleaver-Brooks Co., 326 E. Keefe Ave., Milwaukee 12, Wis. (Jan. '44) *PR*

Lawson, Hugh C., Rensselaer Valve Co., 3807 San Fernando Rd., Glendale 4, Calif. (Apr. '37)

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Ludwig, Harvey E., Office of Surgeon Gen., U. S. Public Health Service, Washington 25, D.C. (July '49) *Goodell Prize '43. P*

Maley, Alexander B., *see* Carman Sterne Maley Corp.

Maneri, Charles Salvatore, Jr. San. Engr., State Dept. of Health, 6 S. Lake Ave., Apt. B-3-A, Albany, N.Y. (Apr. '50) *PR*

Marianao y Regla, Acueductos de, Carlos M. Calvet, Mgr., General Lee 27, Marianao, Cuba (Corp. M. June '39) *Director '42–'45.*

McBride, Samuel P., Gen. Mgr., Trotter Water Co., 706 Fayette Title & Trust Bldg., Uniontown, Pa. (July '39) *P*

McClintock, John Harper, 305 Lakewood Dr., Baytown, Tex. (Oct. '46) *PR*

McDonald, Thomas W., Zone Supervisor, East Bay Munic. Utility Dist., 2327 Tulare Ave., El Cerrito 9, Calif. (Jan. '50)

McIntosh, Russell, Pittsburgh Coke & Chemical Co., 4557 E. Slauson Ave., Maywood, Calif. (Jan. '50)

McKinney, Ross Erwin, 111 Wild Rose, San Antonio, Tex. (Jr. M. Jan. '49) *P*

McLaughlin, Carroll W., Civ. Engr. & Surveyor, 2045 Hempstead Turnpike, East Meadow, N.Y. (Jan. '51)

Murray, J. J., Jr., Chemist & Bacteriologist, Murray Lab., Box 1087, Greenville, S.C. (July '35)

Nelson, H. Lloyd, U.S. Pipe & Foundry Co., Burlington, N.J. (May '30) *Director '38–'39. Fuller Award '46.*

Niagara Falls Dept. of Water, J. A. Fish, Director, 22 City Hall, Niagara Falls, N.Y. (Mun. Sv. Sub. Apr. '49) *MP*

Quinnell, Fred, 328—3rd Ave., W., Roundup, Mont. (Feb. '22)

Ramirez, Conrado S., College of Eng., Univ. of the Philippines, Diliman, Quezon City, P.I. (Jan. '47) *PR*

Randlett, Fred Morse, 1207 S.W. Broadway, Portland 5, Ore. (June '20)

Reeves, Carroll F., Pacific Coast Sales Mgr., De Laval Steam Turbine Co., 160 Folsom St., San Francisco 5, Calif. (Apr. '46)

Rowe, Ernest J., 110 Maple Ave., Wellsville, N.Y. (June '21) *Fuller Award '44. MP*

Sawyer, Robert W., Engr., 46 Ferncliff Rd., Scarsdale, N.Y. (Oct. '32) *PR*

Senseman, Harold L., 11 Morgan Dr., Battle Creek, Mich. (May '27)

Settle, Lester L., Asst. San. Engr., State Dept. of Health, 2044 N.W. 30th, Oklahoma City, Okla. (Jan. '48) *P*

Sloan, Garrett, 5114 King William Rd., Richmond 25, Va. (Apr. '42)

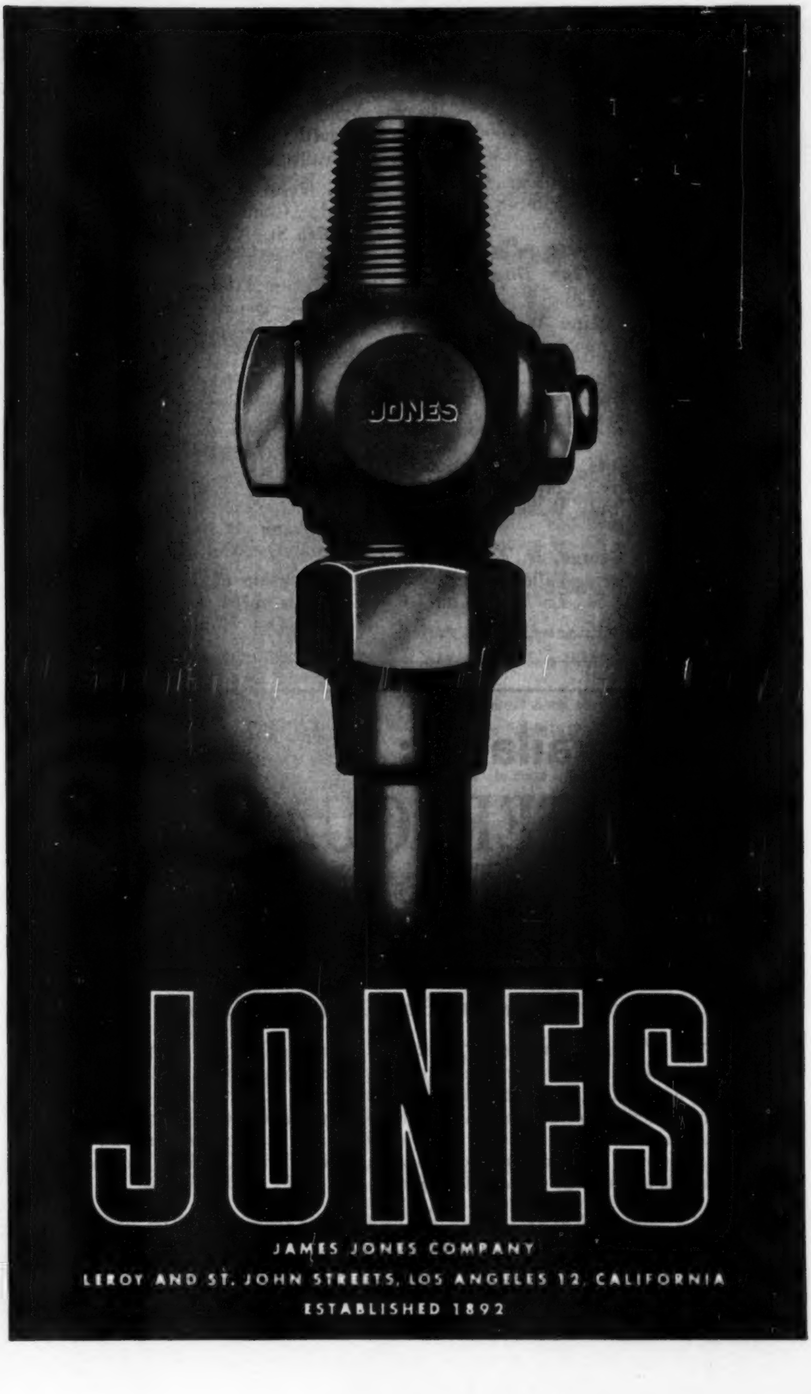
Snow, Bayard F., 1615 DuPont Bldg., Miami 32, Fla. (Apr. '36) *R*

Snyder, Raymond H., Asst. Prof., San. Eng., 105 Packer Hall, Lehigh Univ., Bethlehem, Pa. (July '43) *MP*

Spaulding, Charles H., 611 W. Delaware Ave., Urbana, Ill. (July '24) *Goodell Prize '33. Fuller Award '40. P*

Stratton, Roel K., *see* Casper (Wyo.) Board of Public Utilities

(*Continued on page 42*)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Strohmeyer, Joseph S., Water Engr., Bureau of Water Supply, Municipal Bldg., Baltimore 2, Md. (May '22)

Symons, George E., 86 Edgewood Ave., Larchmont, N.Y. (Jan. '32) *MPR*

Touzin, Thomas, Group Engr., Hydrometric Section, 3161 Joseph St., Verdun, Que. (July '48)

Truman, Chester A., 128 Pearl, Walla Walla, Wash. (Dec. '26) *Director '37–'40. Fuller Award '45.*

Wall, George W., Water Works Engr., 405 City Hall, Birmingham, Ala. (July '45) *M*

Warder, Charles, Supt. of Water Works, 2490 Thorold Rd., Niagara Falls, Ont. (Jan. '16)

Watt, Dan M., Chief, Constr. Section, Water Supply Div., Corps of Engrs., 1st & Douglas Sts., Washington 25, D.C. (Jan. '49)

Watters, Clarence George, Jr., La Mesa, Lemon Grove & Spring Valley Irrigation Dist., 4769 Spring St., La Mesa, Calif. (Oct. '49) *M*

Welday, Chapline F., Asst. Engr., Havens & Emerson, 27822 Aberdeen, Bay Village, Ohio (Jan. '48) *PR*

Westgarth, Warren C., 2657 Harrison St., Corvallis, Ore. (Jan. '51)

Wiley, John S., U.S. Public Health Service, Communicable Disease Center, 50—7th St., N.E., Atlanta 5, Ga. (July '43) *P*

Wilkes, John Frederick, Tech. Director, Railroad Dept., Dearborn Chemical Co., Merchandise Mart Plaza, Chicago 54, Ill. (Oct. '37) *P*

Wolff, William R., Chief Hydr. Engr., N.Y. Public Service Com., 233 Broadway, New York 38, N.Y. (Mar. '30) *M*

Wood, Alan A., Pres., Alan A. Wood, Inc., 4610 N. 15th St., Philadelphia 40, Pa. (Jan. '44) *P*

Wood, Frank B., 905 Coventry Rd., Decatur, Ga. (Oct. '42) *P*

York, Township of, O. M. Falls, Comr. of Works, 2700 Eglington Ave., W., Toronto, Ont. (Corp. M. July '32)

Condensation

Key: In the reference to the publication in which the abstracted article appears, 39:473 (May '47) indicates volume 39, page 473, issue dated May 1947. If the publication is paged by the issue, 39:5:1 (May '47) indicates volume 39, number 5, page 1, issue dated May 1947. Abbreviations following an abstract indicate that it was taken, by permission, from one of the following periodicals: *B.H.—Bulletin of Hygiene* (*Great Britain*); *C.A.—Chemical Abstracts; Corr.—Corrosion; I.M.—Institute of Metals* (*Great Britain*); *P.H.E.A.—Public Health Engineering Abstracts; S.I.W.—Sewage and Industrial Wastes; W.P.A.—Water Pollution Abstracts* (*Great Britain*).

PUMPS AND RELATED EQUIPMENT

Pumped Storage. William J. Rheingans, Frank Jaski & Herman Roth. An unpublished paper presented at Midwest Power Conference, Chicago, Ill. (April 5, '51). Pumped storage is storing water by pumping into specially constructed or natural reservoirs to use subsequently for power generation. Takes water from a river, lake or reservoir and pumps it to a reservoir at greater height. At allotted times, water is allowed to flow back through a turbine. Project acts as huge storage battery. Compared with elec. storage batteries or other accumulators, system has greater flexibility and is probably more economical. Advantages can be summarized as follows: utilizes surplus power available during off-peak periods and transforms it into daytime peak energy, assists in running thermal stations at continuous uniform load and adds to reserve capac. of system. Idea of pump storage not new since installations recorded in Switzerland from 1892. Considerable research work recently done on reversible turbine pump units for use if a single runner hydraulic unit operates in one direction as pump and in another direction as turbine. Hydraulic unit is then connected to a single elec. unit serving as a motor for pump operation and a generator for the turbine operation. Model tests show this type unit would give approx. same eff. when operating in one direction as pump as when operating as turbine. Max. eff. approaches closely the max. eff. of std. pumps and turbines. This reversible pump turbine makes pumped storage attractive in the U.S. because it reduces overall installation costs. Several reversible pump turbines in operation and addl. units being mfd. currently.

Design and Construction of New Booster Pumping Station at Winnipeg. N. S. Bubbis & H. Shand. Eng. Cont. Rec., 64:6:64 (Jun. '51). Shoal Lake 96.5-mi. aqueduct of Greater Winnipeg Water Dist. has capac. of 85 mgd. in upper swampy, barren reaches. From Deacon, site chosen for future 250-mil.gal. reservoir, to Red R. crossing there is 5.5′ lock joint concrete pipeline with capac. 50 mgd., which eventually will be duplicated. Capac. of concrete delivery pipes through city 28.5 mgd. Five overflow structures and surge tank on bank of Red R. provide protection against excessive pressures. Original plan contemplated supplementing gravity flow by booster pumping when consumption reached 25 mgd., estd. for about '22, and subsequent enlargement of lower sections of aqueduct at 50-mgd. consumption. Rate of pop. increase not maintd. and revised ests. provided for constr. of booster station in '50, second pipeline from Deacon by '64, gravity supply again until '76, and supplementary booster pumping thereafter. Booster station, just completed, described. Equip. includes 3 pumps, 20-mgd. capac. each, operating against 30′ head, direct-connected to squirrel cage motors, and selector switch which permits use of only 2 at one time, thus reducing connected

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load. Later, 3 may be used and provision made for installation of fourth unit. Piping is welded steel, 42″ diam., coated with "A-A" coal tar enamel and wrapped with asbestos felt paper dipped in enamel, whole being carefully checked for "holidays." Soil has high SO_4^{--} content and is extremely corrosive. Pump efficiencies 91–92%. Motors can be operated continuously at 15% overload.—*R. E. Thompson.*

Remodeling Winnipeg Pumping Station to Meet Increased Demands. F. L. Morton. Munic. Utils., **89**:4:25 (Apr. '51). Dist. system of 340 mi. mains supplied by 2 stations, James Ave. and McPhillips St., resp. Latter, which supplies 80% of demand, situated where aqueduct terminates in 3 reservoirs, 58 mil.gal. combined capac. Station designed for 7 pumps, 6 of which installed, space for seventh being utilized for Cl and NH_3 machines which deliver to suction main. Plans prepd. early in '50 for addn. to bldg. to house these machines, as space required for addnl. pump. With warning of flood, plans changed to include space for 500-hp. diesel engine direct connected to 314-kva. alternator which was ordered May 7 and in operation in open on May 16 to ensure continuity of power while parts of distr. system below river level. Station can be protected against flood up to 20′ above min. flood level, el. which Red R. reached in 1826. Emergency setup operated continuously 700 hr. during flood and Cl dosage tripled. Addn. now completed. Ventilating system for treatment room provides for complete air change every 3 min. Starting equip. for diesel engine consists of air-

(*Continued on page 48*)


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operated motor connected to pneumatic tank supplied by gasoline-engine-driven compressor. Thus is independent of any other power source: all auxiliary services may be operated by power generated. Maxim residential muffler installed on roof to reduce noise and precautions taken to elim. vibration.—*R. E. Thompson.*

Hydroelevators (Jet Pumps). JERZY ROLEWICZ. Gaz, Woda i Tech. Sanit. (Poland), 24:367 (Oct. '50). Increased usage of jet pumps or hydroelevators in practice. Examples and curves illustrate methods of computing nozzle and throat diams. and for designing pumps.—*C. P. Straub.*

CORROSION AND CORROSION CONTROL

The Use of Asbestos-Cement Pressure Pipe to Combat Soil Corrosion in Winnipeg. W. D. HURST. Wtr. and Wtr. Eng. (Br.), 55:90 (March '51). Winnipeg, pop. 235,000, water supply is delivered to reservoir system by gravity from lake through concrete aqueduct 96 miles long. Water soft and noncorrosive. Daily consumption 19.5 mgd. (Imp.) soil lacustrine and alluvial silt overlying glacial till. Is rich in carbonate of lime. Principal salt deposits encountered in shallow excavations include objectionable sulphates of calcium, magnesium, and sodium. Soluble sodium, magnesium, and calcium salts among chief causes of high corrosiveness. Action on underground pipe where water dissolves soil salts. Solution then acts as electrolyte with metallic constituents of pipe walls and fittings. Electrolysis another major factor causing deterioration of pipe material in Winnipeg. In 1899, City assumed ownership of water works. Approx. 20 mi. of c-i. water main, much of which imported from Scotland, was laid. Metal-to-metal driven joints and bell-and-spigot joints calked with lead types used.

(*Continued on page 50*)

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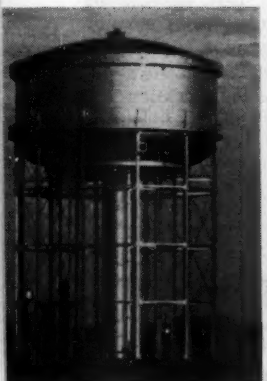

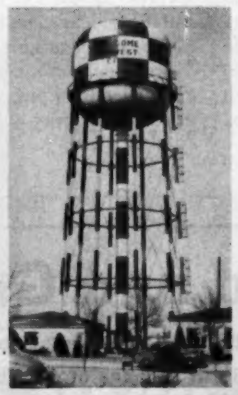

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SANTA CLARA, CAL. . . 631 Alviso Road

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Soon became evident water mains being destroyed by corrosion. Then (about '06) believed corrosion caused solely by d-c. electrolysis. Eventually apparent electrolysis not sole cause of corrosion. In '10, part of Portland cement concrete sewer collapsed. Strong indication damage was from external source. Only solution was to backfill sewer trench with gravel and drain damaging water from concrete. In '13, constr. commenced on 96-mi. concrete aqueduct of Greater Winnipeg Water Dist. In '19, alk. ground water attacked external surface of aqueduct. A. G. Fleming able to replace tricalcium aluminate in Portland cement largely with tetra calcium alumino ferrite which was resistant to alkali solns. Produced commercially satisfactory sulphate-resisting cement, marketed as Kalicrete. No serious alkali disintegration of concrete made with Kalicrete experienced since first used in Winnipeg. Shipley and Blackie concluded soil corrosion of water mains definitely established. Backfilling c-i. water mains with gravel and underdraining them would protect them in the same way as protected concrete. Difficult to find a coating for cast iron that would stand up to temp. differences. In this area (+100° to −35°F.). Tests to demonstrate resistance of asbestos-cement pipe to soil corrosion were made in lab. for approx. 1 yr. with satisfactory results. In '32, trial line consisting of 752 ft. of 18-in. and 431 ft. of 14-in. Class C Transite pipe laid in street with particularly corrosive soil. Conditions aggravated by severe electrolysis from close proximity of elec. substation. In '37, trench opened and pipe carefully examd. No indication soil had deleterious effect on pipe. In Nov. '46, extensive investigations undertaken, with following results: no flow capac. loss, no softening of pipe, pressure tests showed failure at 325 and 430 psi. int. pressure, no leakage from coupling and pipe when tested at 260 psi., pipe sustained 10,260-lb. max. ext. load before crushing, resisted 4,610-lb. force before breaking outward and freeing corporation cock, soundness of rubber rings was substantiated by pressure tests. Use of asbestos-cement pipe best answer so far for local corrosion problem. Cracking can be reduced by better laying and backfill methods together with other improvements still in study stage.—*H. E. Babbitt.*

Stray Currents. EMIL WINTER. Gaz, Woda i Tech. Sanit. (Poland), **24**:416 (Nov. '50). At point stray currents leave water pipe, corrosion will take place unless pipe is protected since pipe acts as anode. Two methods of control suggested: location and removal of stray currents, and location

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of points where stray currents leave pipes and prevention of corrosion by providing suitable protective devices. First not very feasible because sources widespread. Sources should be located and owners of equip. should be cited to make necessary changes in elec. equip. and app. During 15–20 years before '35, all action in locating sources of stray currents. Effort since has been to locate exit points and to eliminate corrosion. Insulation of pipe does not help much. Use made of cathodic protection in U.S. and U.S.S.R. Another method is to decrease pipeline potential below potential of soil. Is expensive and risk remains if maintenance inadequate. Another method for use under Polish conditions is simple, cheap and effective. If pipe potential is higher than soil potential, pipe should be grounded at the point where stray currents leave, and they should be carried to ground. All pipe potential will be carried to ground without damage to pipe. Cu_2O and selenium rectifiers are used. Method convenient, requires no maintenance, functions well and positively and permits carrying stray currents from pipe without harm to other underground facilities. Protective pipe which extends 2 m. to either side of train or trolley tracks can also be used. Under Polish conditions, electric trolleys and trains are main stray current sources. Effects may be combatted by using largest possible insulators placed under rails, using large copper cable conductors properly maintained and reducing rail-ground in potential. In installing new water lines, select routes as far from electric trolley and rail lines as possible to minimize possibility of stray currents, avoid wet, acid and soils which are good conductors (if necessary to run lines through such soils, drain and replace cut with clean sand fill), use protective pipe where rail and water lines cross, (4) ground points where stray currents leave pipe

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and install selenium or other rectifiers to prevent return of stray currents to pipe where ground may have the higher potential.—*C. P. Straub.*

Cathodic Protection. J. MULDER. Water (Neth.), **34**:241 (Nov. '50). Discussion of theory and practice of cathodic pipe protection. Conclusion. Although this method of corrosion prevention is valuable it is not a cure-all.—*W. Rudolfs.*

Electrolysis in Connected Aqueducts. D. HENDRICKSON. Eng. News-Record, **145**:27 (Dec. 28, 1950). Parallel operation of bituminous-coated steel pipelines can generate large galvanic currents in soil of low resistivity. Demonstrated recently when serious water leakage in the 25-year-old Mokelumne aqueduct began shortly after construction of parallel line. Electrolytic action stopped by placing insulated joints in cross connections between lines. This broke elec. circuit that developed. Galvanic current of 16 amp. was discharging from bituminous-coated pipe over 2,500 ft. Current was discharging through cracks caused by soil stresses in coating. Soil was heavy adobe with resistivity as low as 200 ohms per cm. Partial explanation is that concrete-coated pipe tending toward alk. side formed cathode. This picked up current from low-resistance soil over quite a stretch of line. Current increased as a cross-connection was approached. On other side, old bituminous-coated pipe being more acid in nature formed an anode. Current was discharged from pipeline back into ground over a long stretch. —*P.H.E.A.*

The Corrosion of Domestic Galvanized Hot-Water-Storage Tanks. I. LAIRD NEWELL. J.N.E.W.W.A., **65**:71 ('51). Conditions affecting the permanent value of galvanized tanks are considered. Excessive operating temps., presence of Cu in the supply system, and bicarbonates and nitrates in the incoming water are the principal causes of corrosion. Several methods to reduce corrosive trouble are suggested. In the discussion, several cases are described.—*C.A.*

SOFTENING AND IRON REMOVAL

Removal of Iron from Water. P. H. BOUTHILLIER. Munic. Utils., **89**:1:28 (Jan. '51). In many mfg. processes, allowable concn. of Fe in water much less than 0.3 ppm. permitted by U.S.P.H.S. stds. Theoretical considerations governing soly. of Fe discussed and computed soly. of Fe^{++} and Fe^{+++} at pH values 3–9 tabulated. Na exchange zeolites will remove 3–4 ppm. Fe^{++} without injury to zeolite. Fe^{+++} coats zeolite and reduces its life and eff. Most common method of removal aeration and filtration, soly. of Fe^{++} being much less than of Fe^{+++}. Soly. decreases with increasing pH, hence CO_2 removal or addn. of lime reduces soly. Math. equations for 0 intake and CO_2 removal through aeration given. 0 required for oxidation of Fe very small, 0.14 parts per ppm. Fe: reaction very rapid: 50% satn. with 0 adequate for Fe removal. Pptn. hastened by contact with previously oxidized material: submerged contact beds most efficient. Coke commonly used: aging period required. Settling period of little value unless Fe concn. 20 ppm. or more. Final step filtn. through sand: coarse sand (effective size 1.5 mm., uniformity coef. 1) satisfactory if for Fe removal only, but expansion during backwash difficult unless air-water wash used. Calgon prevents Fe pptn. Fe contamn. due to corrosion of pipes controllable by lime addn. to point of satn. with respect to $CaCO_3$.—*R. E. Thompson.*

Modern Lime Process Water Softener. ANON. Wtr. and Wtr. Eng. (Br.) **55**:125 (April '51). Permutit

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Spiracter is lime process water softener of revolutionary design. Is compact, clean, and pressure operated. Features previously associated only with base exchange softeners. Embodies small closed tank which gives reaction time of only 10 min. Softening carried out at atmospheric temp. using normal reagent—lime—and softened water clarified with filters in usual way. *In Spiracter, reaction between raw water and chems. takes place in presence of dense bed of catalyst granules retained in violent agitation by water flow. Pptd. calcium carbonate crystallizes at once on granules and only traces of finely divided sludge remain in suspension.* Utilizes small, closed, conical reaction tank containing charge of silica sand coated with calcium carbonate. Grains held in suspension by upward flow of water, entire bed being lifted to height determined by upward veloc. Lime prepared as emulsion in cylindrical tank with continuously running agitators, then injected into softener at constant rate. With calcium carbonate crystals on, grains grow, and it is necessary to blow off some of bed to retain total vol. within prescribed limits. Avg. size of grains limited by adding small amt. of fresh sand at regular intervals. Filters used for final clarification are of orthodox type. Removal of residual hardness effected by passing effluent through base exchange softener producing zero hard water of controlled alky. and reduced dissolved solids.—*H. E. Babbitt.*

Iron and Manganese Removal in the Spaulding Precipitator. R. H. BABCOCK. J.N.E.W.W.A., **64**:138 ('50). Results are given of pilot-plant expts. using Spaulding precipitator for removal of Fe and Mn from Boulevard well water at Lowell, Mass. The water (pH 6.3) contains 4.4 ppm. of Fe and 0.8 ppm. of Mn. The precipitants used are $Al_2(SO_4)_3$ and CaO, the pH is kept between 8.5 and 9.1. Fe and Mn removals of approx. 95 and 99%, resp., obtained. Hardness of water was increased from 50 to 100 ppm. but by use of Na_2CO_3, or Na_2CO_3 + CaO, water of any desired hardness from 50 to 100 ppm. could be produced. Comparison between these results and lab. jar tests showed that conventional chem. pptn. was less efficient for removal of Fe and Mn. Use of the Spaulding precipitator results in large savings in chems.—*P.H.E.A.*

CHEMICAL ANALYSIS

Determination of Calcium and Magnesium Hardness in Water by Direct Colorimetric Titration. J. JEFFREY WALKER & V. MURTAGH. Wtr. and Wtr. Eng. (Br.), **55**:8 (Jan. '51). Titrimetric method for separate detn. of calcium and magnesium contents of water. Method simple, rapid and gives accurate results within 2%. Method should prove useful in evaluation of base exchange materials. In detn. of total calcium and magnesium hardness titrating soln. employed is alk. soln. of disodium salt of ethylenediaminetetracetic acid, commonly known as versene. Titration continued until last drop of red color has disappeared. Addn. of more titrating soln. should not show any further color change. Total hardness, as ppm. $CaCO_3$ equals (titration × 1,000) (vol. of sample). In detg. calcium hardness same titrating soln. used, indicator being sensitive to calcium ions only. Fresh standardization of versenate being made using "Murexide" as indicator. Titrate until end point changes from pink to purple. End point sharp and readily detected. Calcium hardness equals (titration × factor) (volume of sample). Difference of opinion exists among operators in U.S. on best way to avoid interference due to other ions. Two main methods appear to be use of sulfide borate buffer and use of $NH_4(OH)NH_4Cl$ buffer with various addn. of other complexing reagents to

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prevent specific interference due to any 1 metal. Former method found satisfactory. End point is not always red-blue or pink-purple change. If chromate is present end point is green. It is perhaps better with colored impurities to regard end point as no further color change.—*H. E. Babbitt.*

Standards for Expressing the Results of Physical, Chemical and Bacteriological Examination of Drinking Waters. A. LeStrat & J. P. Buffle. Intern. Water Supply Assn. Congress, Amsterdam ('49). Summaries of reports on chem., phys. and bact. qual. of water supplies in Australia, Belgium, Great Britain, Ireland, the Netherlands, Sweden and Switzerland given and discussed in relation to standardization of analytical methods, the max. allowable content of the various constituents and the expression of results.—*W.P.A.*

Determination of Color of Turbid Waters. W. L. Lamar. Anal. Chem., **21**:726 ('49). True color of turbid waters must be assessed after turbidity is removed, as it gives an apparent color which may be higher than the true. Turbidity of many natural waters cannot be removed by centrifuging. Method described in which calcium chloride is used to coagulate sols which can then be removed by centrifuging. Color then detd. by the usual method with platinum-cobalt std. Tests showed presence of calcium chloride did not affect true color.—*W.P.A.*

Colorimetric Estimation of Iron. B. Sen & A. K. Majumdar. Sci. & Cult., **15**:163 ('49). Colorimetric

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method for the detn. of ferrous iron based on the formation of a red complex with quinaldinic acid. Complex is dissolved in excess cyanide, which intensifies color, and is examd. in a photoelectric colorimeter.—*W.P.A.*

The Volumetric Determination of Silica. H. N. WILSON. Analyst, **74**: 243 ('49). A volumetric method for the detn. of silica described in which silica is converted to silicomolybdic acid and ppd. as quinoline silicomolybdate from a strongly acid soln. The quinoline silicomolybdate is dissolved in excess of std. sodium hydroxide soln. and excess titrated with std. acid soln. Method rapid and has std. deviation of 0.048.—*W.P.A.*

Photocolorimetric Methods for Determination of Ammonia in Drinking and Waste Water. M. I. KULENOK. Gigiena i Sanit., **10**:45 ('50). The photocolorimetry of NH_3 with Nessler's reagent in natural waters gives precision only with very thick layers of the soln. (12–15 cm.). Berthelot's method, using phenol-hypochlorite procedure, gives good results with a 6-cm. layer. Substitution of thymol for PhOH and hypobromite for hypochlorite permits examn. of colored solns., although accuracy suffers seriously.—*C.A.*

BACTERIOLOGY

What a Waterworks Man Should Know About Bacteriology. A. S. RICHARDSON. Munic. Utils., **89**:3:29 (Mar. '51). Human excreta contain avg. of 125×10^9 *E. coli* per person in summer and 400×10^9 in winter. Longevity and rate of destruction of *E. coli* by natural and artificial purif. processes about same as *S. typhosa*, hence used as criterion of water qual. Coliform group include plant and soil types: fairly reliable differentiation can be effected with E.M.B. or Endo Agar and positive identification with IMViC tests. Presence of *E. coli* generally accepted as proof of fecal origin of contamn. Possibility of *E. coli* existing and multiplying under natural conditions on watersheds other than in animal intestine not accepted, nor is "impossibility" of human contamn. on controlled watershed admitted, irrespective of however close the control and however remote the possibility. That *E. coli* may be of animal origin possible, but no chance should be taken. Fish carry *E. coli* in intestines, as do waterfowl. Tularemia from infected beaver has on rare occasions been known to infect human pop. through water supply. Chlorination of surface supplies, however free from known contamn., increasingly regarded in same light as fire insurance. Samples should be collected from points in distr. system spaced to represent approx. equal quants. of water consumed for drinking purposes and examd. immediately or shipped packed in ice. Negative results from samples more than 24 hr. old should be considered unreliable: M.P.N. of such samples may be too low. Basis of U.S.P.H.S. std. discussed briefly. Requirement that not more than 10% of 10-ml. portions examd. shall contain coliforms in effect requires M.P.N. of not more than 1 per 100 ml. Coliforms in 3 or more of 5 10-ml. portions constituting std. sample would occur by chance 0.85% of time with water contg. 1 coliform per 100 ml. Has been estd. that for every million coliforms in sewage there are 3–120 *S. typhosa*, number depending upon typhoid morbidity in tributary pop. Thus, if all coliforms recovered from water supply were of sewage origin, water meeting std. might be expected to contain 1 *S. typhosa* in each 13,000 l., or 2940 gal., for incidence of typhoid in Canada. With avg. consumption of 1 pint per day as drinking water, 1 person each day in every 23,500 would ingest a

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typhoid organism. This might be expected to give rise to 1 case of typhoid daily in each 1.5 million pop. This rate is much higher than occurs because many coliforms originate from animals while *S. typhosa* is peculiar to man alone. Residual of danger always exists, and water quality should be superior to stds. This is not difficult with adequate plant, trained personnel and conscientious operation. Having done so, prevention of recontamn. through cross connections and new and repaired mains vitally important. Nine references.—*R. E. Thompson.*

Note on the Estimation of Bacterial Populations. P. B. HUTCHINSON. New Zealand J. Sci. Tech., **30**:81 ('48). Numbers of bacteria in liq. can be estd. by directing a narrow beam of light through cultures, contained in special tubes, to a photoelec. exposure meter which is calibrated against cultures with known bact. pop. A curve correlating numbers with relative opacities can be drawn.—*W.P.A.*

Chlorine Stability of Bacteriophages of the Alimentary Group. L. A. PAPKOVA. Gigiena, **2**:49 ('50). Intestinal bacteriophages are not affected by contact for 1 hr. with the doses of chlorine commonly used in water purif. Their activity is reduced only by doses of 25–50 mg. of chlorine per l. Chlorine is more effective for this purpose than calcium hypochlorite.—*W.P.A.*

Indicator Organism. C. S. MCCLESKEY. Louisiana State Univ., Eng. Expt. Sta. Bul. Ser., **21**:35 ('50). Possibilities of organisms other than *E. coli* for indicating degree of water poln. are considered. Enterococci in-

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dicate heavy pollution more sharply than do coliforms. Neither seem to multiply in surface waters.—*C.A.*

CANADIAN WATER SUPPLIES—GENERAL

Water Supply Improvements for Canada's Capital. ANON. Munic. Utils., **89**:2:17 (Feb. '51). Data from report by Gore and Storrie, Consulting Engrs., on water supply system of Ottawa in relation to master plan for development of city and environs. Area over which unified control of services should be established, as defined by Planning Area Board, embraces 47,000 acres, about 9 times area of city. Present source of supply, Ottawa R., must be continued and all sources of poln. should be elimd. River approx. 700 mi. long, with total watershed 56,000 sq.mi., of which 35,000 above city. Water seldom turbid but has color 40–60 ppm.: avg. alky. 23 ppm., hardness 35–38, pH 7.1, temp. 32–82°F. Large flow and numerous lakes favorable to natural purif. and sanitary qual. superior to most large rivers near urban centres. Existing system supplies 190,000. On Lemieux Island, 42-mgd. purif. plant, 6-mil.gal. clear water reservoir and high-lift station. Water pumped into system by latter or flows by gravity to Queen St. hydraulically driven station. Combined high-lift capac. 138 mgd. In addn. to high-pressure fire system, 1 booster station at Carling Ave. Distr. entirely by direct pressure, without elevated storage. Consequently filter plant cannot be used to capac., nor can full clear-water reservoir capac. owing to necessity of maintg. sufficient head for gravity flow to Queen St. Station. Filter plant designed for doubling capac., and this can be effected in 3 stages. Through active waste and leakage reduction program, per capita consumption declined steadily from 200 gpcd. in '20 to 109–112 in '35–'43. Since then leak-detection activities curtailed by manpower situation and consumption increased to 132 gpcd. in '48. Expected that comprehensive leakage survey recently commenced will again reduce water use. Severe climate major cause of breaks and leaks in mains and services. In city, where few residential services metered, consumption 143.5 gpcd.: in Nepean Township and Rockcliffe Park, where all services metered, 40 and 90, resp. In addn. to effect of metering, city rate reflects industrial and commercial use and also influence of transient and commuter pop. Avg. consumption in '48, 24.87 mgd.; 3 successive days in Feb., 28.5–29 mgd.; in Aug., 27.5–28.4. Need for metering more and more apparent; is most effective means of reducing waste. Recommended that 24-mil.gal. covered concrete reservoir be constructed at Carlington Heights with top water level at El. 370 or 190′ above floor of Queen St. Station, together with necessary feeder mains to supply reservoir and strengthen system. Estd. cost of improvements $5,972,000, of which $1,200,000 for reservoir and remainder for mains.—*R. E. Thompson.*

The Story of the St. Catharines Water Works System. St. Catharines Waterworks System, St. Catharines, Ont. (1951). First system, delivering water from Welland Canal through bored pine logs chiefly for fire protection, completed 1850. In 1875, initial step in constr. of present system at Decew Falls: water drawn from Beaver Dam Creek, later supplemented by water from Old Welland Canal. In 1902–03, original power channel of power company ending in Gibson Lake at top of 170′ Niagara Escarpment acquired, making possible supply direct from Welland Canal at Allanburg without mixing canal water with runoff from watershed. Pipeline, 16″ diam., delivered water from reservoir to city by gravity. In '12, second de-

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livery line constr., 24″ diam. laid in 5 × 7′ tunnel 4,234′ long. Another 24″ line laid in tunnel in '46. Combined capac. of 3 mains 16 mgd., providing 50-psi. pressure in central part of city. Chlorination adopted in '14 (present app. automatic) and in '26 10-mgd. rapid sand filter plant installed consisting of 3 low-lift pumps (20-mgd. capac. total), baffled mixing basin, 2 coagulation basins and filters contg. 15″ gravel and 30″ sand. Alum used as coagulant and filters backwashed every 18 hr. Pop. 37,155, area of city 3,670 acres. Avg. consumption 7 mgd., 110–115 gpcd. for domestic purposes and 70–80 gpcd. for industrial use. In '49, premises served 9,745, mains 90.5 mi., hydrants 560. Domestic use unmetered: rates lowest in Canada. Plant value more than $2,500,000. Administered by elected commission of 4 members and mayor (exofficio).—*R. E. Thompson.*

Nine Municipalities in Winnipeg Area Coöperate in Obtaining Water. N. S. Bubbis. Munic. Utils., **89**:4:33 (Apr. '51). Prior to formation of Greater Winnipeg Water Dist., 5 of 9 municipalities comprising dist. supplied by Winnipeg and 1 by St. Boniface. Supply of latter from wells, that of Winnipeg from Assiniboine R. and later from wells. River supply turbid and unpalatable, well supply hard. Municipal ownership since 1899. Indian Bay-Shoal Lake-Lake of the Woods aqueduct commenced as joint undertaking in '13 and completed in '18. Area of supply lakes 1,500 sq.mi. and of watershed 28,060 sq.mi. Aqueduct: 77.5 mi. cut-and-cover concrete, capac. 85 mgd.; 7.1 mi. river siphons (8 crossings) and pressure section, 85-mgd. capac.; 9.4 mi. reinforced concrete pressure pipe, 50-mgd. capac.; 0.2 mi. Red R. crossing, 5′ c-i. pipe in concrete lined tunnel; 2.3 mi. 4′ concrete pipe in Winnipeg; total length 96.5 mi.; el. of intake above Winnipeg Res. 290′; flow time (30 mgd.) 51 hr. Dist. has rights to 100 mgd. NH_3-Cl (1:4) treatment in Winnipeg and St. Boniface to give 0.4 ppm. residual. Financed by assessed rate on land and bulk charge of 5¢ per 1,000 gal. Municipalities represented on admin. board. Bonded indebtedness $13,927,-113, sinking fund assets $7,313,921. Avg. consumption 76 gpcd.—*R. E. Thompson.*

Prestressed 84-in. Concrete Pipe for Montreal Waterworks Intake. David A. Hopkins. Munic. Utils., **89**:5:25 (May '51). Nearly 2 mi. pipe, wall thickness 5.5″, fabricated. Sections precast, wound with prestressed wire while being revolved on turntable and protective layer of gunite applied. Procedure similar to that used for prestressed concrete tanks.

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Absence of tension cracks in permanently compressed concrete renders prestressed constr. eminently suitable for water-retaining structures. High tensile strength wire and high strength (to 9,000 psi., 28 days) concrete employed. Typical circular tank is 70′ diam. and contains 17′ water, yet wall thickness only 4.75″. Tanks to 320′ diam. with water depth to 50′ have been constructed. Floor of ordinary reinforced concrete 4″ thick or gunite 2″ thick, reinforced with welded wire mesh and without expansion joints. After hardening of unreinforced walls, circumferential wire, 0.162–0.235″ diam., tensioned to 140,000 psi. by drawing it through die which reduces diam. approx. 10%, wound into place. Vertical wire reinforcement laid in slots in walls and tensioned by jacking, whole then gunited. Walls designed for residual compressive stress of 50 psi. when tank full. When domed top required, concrete, reinforced with welded wire mesh, poured on forms, with substantial concrete ring incorporated at base of dome and resting on wall. Several layers wire wound on ring, with intermediate layers of gunite, this prestressing lifting dome clear of formwork. Quants. of concrete and steel required about 50 and 20%, resp., of that for reinforced concrete tank and cost usually less.—*R. E. Thompson.*

A Brief History of the Greater Winnipeg Water Supply. Eng. Cont. Rec., **64**:5:82 (May '51). Water supplied in bulk to Winnipeg from Shoal Lake system of Greater Winnipeg Water Dist., treated with NH_3 and Cl. Winnipeg system includes 353 mi. mains, 3,440 main valves, nearly 54,000 services, mostly metered, 3,045 hydrants. Pressure 75 psi. Separate fire-protection system, with 12.8 mi. mains and 161 hydrants, operates at pressure to 300 psi. Reservoirs, 18 mil.gal. covered and 40 mil.gal. open.

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operated in series, functioning as settling basins and providing contact period for chemicals. Life of c-i. pipe in corrosive, alk. soil not much more than 40 yr.: serious corrosion often in 10–12 yr. Main breaks avg. 180 per yr. Transite pipe, found free from deterioration after 15 yr. service, being substituted for cast iron. Frost penetration sometimes more than 7′. Min. main cover 7.5′. Wrought Fe and galvanized services corrode quickly; Pb becomes brittle in 30–40 yr.; life of Cu, used since '24, not known. Min. depth of services 7.5′; approx. 100 frozen each yr.; portable gasoline-driven generator for thawing. All services metered except those subject to continual freezing. Valves located to make possible isolation of any 600′ of main. Hydrants, stop and curb cocks and meter parts fabricated in dept. shops. Hydrants spaced not more than 400′ apart.—*R. E. Thompson.*

FOREIGN WATER SUPPLIES —GENERAL

Rainfall Over Great Britain and Northern Ireland During 1950. JOHN GLASSPOOLE. Wtr. and Wtr. Eng. (Br.), 55:97 (March '51). Rainfall in '50 on England and Wales exceeded avg. by 5.2″ and more than compensated for deficiency of 4.3″ in '49. During previous 82 yrs., only 11 have been wetter. Scotland had 9 wetter years in similar period, most recent '48 with 62.0″. General monthly values show rainfall exceeded avg. over England and Northern Ireland in 6 months, and over Scotland in 7 months. Rainfall of seasonal year

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was less than avg. only at Lowestoft, but exceeded 130% over large part of southwest England, Wales, English Lake Dist., much of western half of Scotland and western half of Northern Ireland.—*H. E. Babbitt.*

The St. Etienne (France) Water Supply. L. Mirassou, La Tech. Munic. et San. (Fr.), 46:46 (Feb. '51). St. Etienne, provided to 1936 with very insufficient and bacteriologically suspicious water by Furan R. and Lignon R., took steps to improve supply. Increased the capac. of dammed reservoir on Lignon R. and completely overhauled the distr. system. Improved the qual. (especially bact.) by inviting 3 water purif. concerns to submit competitive bids after a 9-mo. trial of 3 pilot plants (built by the concerns) on basis of treated water cost with given water characteristics to be attained. Design selected and system built between '46 and '49 includes sedimentation, flocculation by alum and lime, rapid sand filtration and sterilization by chloramines (obtained by mixture of liquid ammonia and chlorine in water). Filters (graded quartz on finely slotted transite false bottom) feature semiautomatic backwash and constant-loss-of-head regulators. Three reservoirs for treated water provided (capac. 2.92 mil.gal.) with plant output of 26.3 mgd. (max. capac. 30.4 mgd.). Raw water characteristics: pH 6.7–7; color brown (caused by recent reservoir enlargement from 192.5 million cu.ft. to 1,400 million cu.ft.); turbidity high (no figures) due to colloidal clay; considerable org. (vegetable) matter (no figures). Treated water characteristics:

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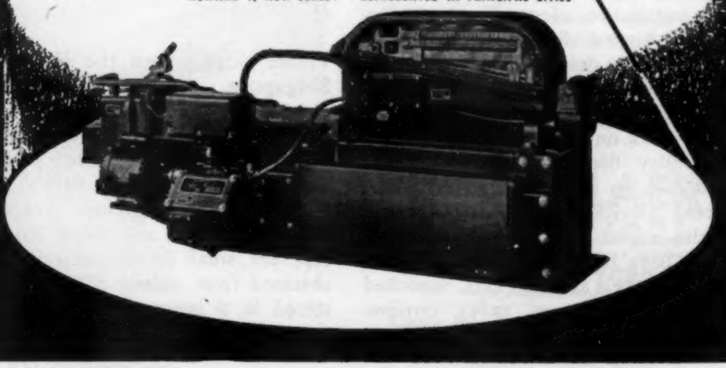

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no color (removal attributed to alum); org. matter decreased 30%; no *B. coli* or bact. in 100 cc.; very few sporulated germs per cc.; no taste; turbidity not exceeding 5 drops of $\frac{1}{1,000}$ alc. soln. of putty in 50 cc. distd. water.—*M. Albanese*.

Lower Nihotupu Water Supply for the City of Auckland. A. D. Meade. Wtr. and Wtr. Eng. (Br.), **54**:229 (Dec. '50). Paper presented to New Zealand Inst. of Engrs. and published in slightly abridged form. Lower Nihotupu Res. most recent addition to water supply headworks. Watershed 3,100 acres with mean annual rainfall of 71″ and stores 1,048 mil.gal. (Imp.) of water. Can yield 6 mgd. (Imp.) throughout most severe drought period. Dam is rolled earth constr., 81′ base to crest with 1,257′ crest. Sidespillway capable of passing 16,300 cfs. at 4′ surcharge above storage level. Supply pumped through rising main 100 chains long of 24″ and 18″ pipes side by side to concrete conduit 382′ above sea level, gravitating to Huia filter plant at Titirangi, extended to take this supply. Supply reaches city through 9 mi. of 30″ and 1 mi. of 24″ steel main with several branches into suburban trunk feeder mains. In '38, mean demand was 10.15 mgd. (Imp.); in '43, nearly 15 mgd. Very dry summer of '42–'43 brought severe crisis and only vigorous economy and hurried installation of auxiliary supplies avoided virtual disaster. Lower Nihotupu dam is only use of lower graded course of Waitakere stream for city supply. Dam site is practically at high water mark on tidal stretch of stream. On valley floor, stream had planed papa rock by migration of meanders. Recent alluvial deposits immediately overlie sound papa. Side slopes of valley have occasional stream terrace beds of gravels and clay silts, deposited at earlier stages of valley erosion. Estn. of limiting flood dischg., 1,970 cfs. per sq.mi. is equiv. to flood of 16,750 cfs. at site. Dam design closely followed modern practice for roll-filled earth dams. Dam site excavation entailed handling 154,000 cu.yd. within 1,000′. For haulage not exceeding 2,000′, tractors and 12-yd. scoops with max. speed of 5 mph. were used. To meet difficulty of wet borrow pits, contractor disced surface to assist drying, and picked up loads by thin skimming cuts of surface material. Shoulder material placed as for core material except mixing with discs omitted and boulders over 9″ diam. removed by pushing over side of dam by blade machine. Dam fill vol. 469,800 cu.yd. Some material testing carried out at Council's field lab. Following acceptance of bid for earth dam fully equipped, soil mechanics' lab. established on site and staffed with analyst and 5 cadets. Lab. work preoccupied with core material, because of predominant use in dam. Reinforced concrete highway bridge provided over spillway channel. Bridge has 67′ clear span, 24′ width, gradient of 1 in 9.2 and skew of 40°. Bids taken on pumping equip. of 5 units of direct-coupled pumps and motors, each capable of delivering 2 mgd. (Imp.) against 380′ head. Six new filter beds added to Huia filter plant, giving 14 beds for normal capac. of 1 mgd. (Imp.) each. Total cost of all works is £687,400.—*H. E. Babbitt*.

Water Supply and the Defence of Singapore. Anon. Wtr. and Wtr. Eng. (Br.), **55**:47 (Feb. '51). Factual story of water supply of Singapore prior to capitulation to Japanese. Despite all adversities, supply maintained throughout period. Water for supply of island and naval base, except for small quant. of salt water, obtained from upland catchments and stored in 6 impounding reservoirs, 3

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on island and 3 on mainland of Johore. Latter, together with pumping station at Pontain Ketchil and filters at Gunong Pulai, known as Johore Works. Water brought from Johore Works to island by 39″ steel pipeline laid along causeway and supplies approx. $\frac{1}{2}$ of total quant. of 33 mgd. (Imp.) normally consumed on island. Most of water flows directly to Pearl Hills Res. and then to 30 mil.gal. (Imp.) service reservoir at Fort Channing. Some diverted to Johore, Bahru, naval base and places across island in route of pipeline. When war was declared by Japan, control room was established in basement of municipal bldg. which enabled direction of work to continue during air raids and shelling. Repair and inspection squads operated 24 hr. daily. Clerical staff allotted special duties to assist outside staff. Rice and other rations distributed and cooking arrangements made for feeding men working long hours. Only minor damage until Dec. 29. Between Dec. 29 and Jan. 17, '42, air raids caused minor damage but no large mains broken. First really serious damage occurred Jan. 17, when series of bombs caused 3 breaks in 39″ pipeline, in one of which 5 20′ lengths of steel pipe were blown completely out. Work continued for $2\frac{1}{2}$ days before repairs made. Other damages later sustained. Water dept. able to cope with air raid damage until shortly before fall. Jan. 31, causeway and lock at Johore end were blown up. Supplies then drawn from island resources. Feb. 10, area around MacRichtie Res. became battleground. Feb. 14, Japanese occupied reservoir bungalow and controlled reservoir. Water supply to Bukit Timah filters was uninterrupted. Peirce Res. area was occupied by Japanese 3 or 4 days before fall, but they did not shut off delivery main and though supply was partly in enemy hands, supply to Woodleigh continued. Pumping station roof at Seletar Res. damaged by bomb and explosion of number of ammunition dumps, but pumping was uninterrupted. Johore works abandoned Jan. 29. Water dept. men last civilians to cross causeway. Attempt made to install new connection to Johore pipeline to supply naval base from Singapore, but interruption of work by air raids and difficulty keeping men at work made it abortive. Damage to communication and service pipes was so extensive immediate repair impossible in last few wk. before Feb. 15. From Feb. 12–15 breaks isolated wherever possible to prevent further leakage. Adequate water available at every fire. Two members of dept. staff and 10 daily employees killed. Three daily paid employees injured. Water situation in Singapore was critical but not out of hand. Engineers and staff stuck to posts to end and upheld tradition of water service.—*H. E. Babbitt.*

The Casablanca (French Morocco) Water Supply. P. Heuriot. L'Eau (Fr.), **38**:64 (April '51). How Casablanca solved postwar water supply problem when existing water-

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sheds, especially the distant adduction from Fouarat (put in service in 1933) proved insufficient. Program conducted in 2 steps. Intake constructed from the Wadi Mellah dam in '46–'47 as provisional measure, due to scarcity of materials and closeness of supply to Casablanca. System comprises a pumping station elevating water 119 m. from dam base into a purif. plant (decantation in inverted cone basins, alum flocculation, primary settling, active carbon addition, secondary settling, rapid sand filtration and chlorination) an adduction main to Fouarat system with pressure-regulating chambers and deaerators. Plant and mains of reinforced concrete; max. output 8.65 mgd. (avg. 4.33 mgd.). Water is slightly saline and treated with 10–40 ppm. alum. Addnl. supply from the Wadi Oum-er-Rbia, ultimately to provide 43.25 mgd. is being achieved in 2 phases. Tunnel being dug from Im-Fout Dam (upper Oum-er-Rbia) followed by mains to Casablanca, crossing river at Bridge Dam Si-Saïd Maachou, both for potable and irrig. water. Total differential el. 91 m. for 126 km. Diam. of mains 1.40 m. and 1.70 m. Pumping of up to 21.6 mgd. of water from the Si-Saïd Maachou Dam up to the same levels as Im-Fout (180m) into purif. plant (primary sedimentation and coagulation in accelator sludge blanket units). Rapid Sand filtration, chlorination and mixing of the waters from Im-Fout and Si-Saïd Maachou will be effected in a 525,000 cu.ft. equalizing tank after passage through treatment plant of the second waters. Main to Casablanca is interrupted by 5 pressure-regulating chambers and ends in 2 reservoirs.

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All mains of reinforced concrete, some with a sheet steel core. Raw water characteristics vary widely due to violent floods and droughts; suspended solids may go as high as 10,000 ppm. —*M. Albanese.*

POLLUTION CONTROL

Need for Protecting Surface Waters Against Pollution. IRENA CABEJSZEK. Gaz, Woda i Tech. Sanit. (Poland), **24**:257 (July–Aug. '50). In Poland, surface waters (lakes, diked ponds and rivers) constitute about 1.6% of land area. Surface waters highly important for strategic, potential power, recreation and transportation purposes. Also used for water supply, fish culture and as outlets for domestic and industrial wastes. Degree of hazard due to dischg. of waste varies, depending upon several factors, most important ones being chem. compn. of waste, amount of wastes dischg. in given interval of time and flow in same time interval. Some effects noted are: physical—color, turbidity, odor; chemical—effect on D.O., toxic elements, corrosion; bacterial—greater numbers, pathogenic organisms; and biological—fish require 30% O_2 satn. Suggested control of poln. by [1] examn. of surface waters to obtain normal compn. and for noting sources of poln., [2] detn. of amount of poln., [3] delineation of limits of allowable poln. or amounts of waste to be dischg., [4] development of waste treatment methods and facilities needed to treat wastes and [5] surveillance of treatment facilities and dischg. of treated wastes. Author defines limnology and need for limnological anals. to note effects on surface waters. Limnological program twofold: [1] field studies for collection of plankton, mud, chem. tests, etc., and [2] lab. study to det. quant. and qual. results of field catch, and to interpret data in

(Continued on page 82)

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terms of limnological knowledge.—*Conrad P. Straub.*

Pollution in Boundary Waters. A. E. BERRY. Munic. Util. (Can.), **88**:9:58 (Sept. '50). International Joint Commission investigation of St. Marys, St. Clair, Detroit and Niagara R. and L. St. Clair outlined. Field labs. established and supplemented by permanent labs. of groups represented on Bd. of Technical Advisers (comprising U.S.P.H.S., Can. Dept. of National Health and Welfare, Michigan, New York State and Ontario). Detns. included coliforms, Cl, phenols, NH_3, Cl demand, D.O., B.O.D., pH, alky., turbidity, oil CN, solids, tastes and odors. Treaty of '09 requires that boundary waters between U.S. and Can. shall not be polluted on either side to injury of health or property on other side. Vol. of sewage and industrial wastes discharged in waters studied 624 and 1728 mgd., resp. Constituents of industrial wastes included 12,990 lb. of phenols per day, 8620 lb. of CN, 70,200 lb. of NH_3 compds., 18,015 gal. of oil, 742,900 lb. of B.O.D., equiv. to 4,400,000 persons.—*R. E. Thompson.*

Phenol and Analogous Compounds. A. V. DELAPORTE. Munic. Util. (Can.), **88**:9:61 (Sept. '50). Industries found to be discharging phenols into boundary waters [cf. previous abstract] included coke, gas, synthetic resins, oil refining, petroleum cracking, wood distn., dye and pharmaceutical. Board of Technical Advisers considered that adequate protection against taste and odor provided if concn. of phenol or phenolic equivalents does not exceed avg. of 2 ppb. at any point in these waters following initial diln., and that this qual. probably attained if plant effluents limited to 20 ppb. Opinions on end-products in destruction of phenols by superchlorination outlined. Treatments for phenol-contg. wastes include sprinkling filters, ClO_2, superchlorination, sepn. by mixing with fuel oil and burning latter, and addn. of NaOH followed by acidification and decantation of phenol. General principles include exclusion of phenols from wastes, reduction of vol. of phenol wastes, recovery of phenol where possible and segregation of phenol wastes from sewage.—*R. E. Thompson.*

WELLS AND GROUND WATER

Deep Wells and Well Equipment. H. N. HAINSTOCK. Wtr. & Sanit. (Can.), **88**:1:27 (Jan. '50). Principles of ground water development in prairies given. Test borings in bedrock should be 8″ diam. min. and test-pumped with turbine pump at or near capac. required. In glacial drift, borings need not be large diam. In limestone, sandstone or sandy shale, tubular type wells suitable, size at least 2″ larger than most efficient pump for quantity desired. Overburden should be cased off. If bedrock sufficiently consolidated, open hole can be drilled, otherwise liner should be used. Much development not possible—blasting probably as effective as acidizing. Gravel wall wells most suitable for

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unconsolidated deposits. Methods of constr. outlined. In corrosive waters, asbestos-cement pipe can be used for inner casing in conjunction with non-corrosive screens. Latter should be as thin as possible consistent with ample strength. Openings usually horizontal and tapering outwards. Deep well vertical turbine best pump for capac. of 25 gpm. or higher. Records of pumping and static levels and capac. advisable. Pumps should be pulled and inspected every 4–5 yr., oftener when water corrosive. Agitation best method of rehabilitating mechanically plugged well—Fe, $CaCO_3$ and $MgCO_3$ removed by HCl contg. inhibitor.—*R. E. Thompson.*

Sample Borings for Natural Resources, Destruction and Salt Contamination of Ground Waters. Emil Winter. Gaz, Woda i Tech. Sanit. (Poland), **24**:259 (July–Aug. '50). Of great value to well drillers searching for water are drilling logs from sample borings in connection with coal, ores, iron, oil, natural gas, etc. Geological data, water flow, and chem. anals. may be learned from good log notes. All sample borings should be sealed tightly to prevent dischg. of waters. Waters dischgd. from mines are generally saline and acid and not suitable for water supply. Author cites examples where in drilling for water, water found at upper levels in insufficient quantity and drilling continued until perhaps saline or contamd. water under greater pressure is encountered, which, if its flow is not cut off, would pollute not only drilled well but also other wells served by upper water-bearing strata. Suggests use of cement to seal saline wells. Problem considered of importance in view of fact that during current 6-yr. program much drilling will be carried out in search for natural resources.—*Conrad P. Straub.*

OTHER ARTICLES NOTED

Recent articles of interest, appearing in American periodicals, are listed below.

Sedimentation at Hydro Reservoirs. Elmer K. Nelson. Pub. Util. Fortnightly, **46**:793 (Dec. '50).

Michigan's Industrial Wastes Control Program. L. N. Rydland. Sew. & Ind. Wastes, **22**:1591 (Dec. '50).

Ground Water Pollution in Michigan. Norman Billings. Sew. & Ind. Wastes, **22**:1596 (Dec. '50).

Utilization of Natural Purification Capacity in Sewage and Industrial Waste Disposal. C. J. Velz. Sew. & Ind. Wastes, **22**:1601 (Dec. '50).

Aerobic Microbiological Corrosion of Water Pipes. Erik Olsen & Waclow Szybalski. Corrosion, **6**:405 (Dec. '50).

Fluoridation of Water Supply Under Consideration at Tampa. Carl J. Lamb. W. W. Eng., **103**:1110 (Dec. 1950).—*P.H.E.A.*

Fluoridation Review. Chlorination Topics, **4**:6 (Nov. 1950).—*P.H.E.A.*

Fluoridation of Public Water Supplies and Its Effect on Dental Decay. Hugo M. Kulstad, John C. Dement, Henry J. Ongerth & Remo Navone. Calif. Health, **145** (April 15, 1951).—*P.H.E.A.*

Industrial Water Supply. Arthur M. Field. Am. City, **66**:110 (April '51).—*P.H.E.A.*

Miami's Hialeah Treatment Plant—1951. Clarence R. Henry. Wtr. & Sew. Wks., **98**:143 (April '51).—*P.H.E.A.*

The Reading Meter

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Fundamental Considerations in Rates and Rate Structures for Water and Sewage Works. *Joint Committee Report. Ohio State Law Journal reprint (Spring 1951) 75¢ from American Society of Civil Engineers, 33 W. 39th St., New York 18, N.Y.*

This 126-page reprint comprises a joint report of committees of the American Society of Civil Engineers and the Section of Municipal Law of the American Bar Assn., together with representatives of A.W.W.A. and five other organizations interested in municipal and utility finances. It is not, however, an official statement by any of the participating organizations.

The document had its origin in the growing realization that rate structures—both existing and proposed for adoption—varied widely and without apparent logical consistency. After nearly three years of work, the committee, under the chairmanship of Samuel A. Greeley and John D. McCall, has produced its report. Chapters survey the general characteristics of water and sewage works, the differences between public and private ownership, the elements of financing them and determining annual revenue requirements, and then both present practice and recommended procedure for setting rates. A chapter on methods for enforcing payment and a summary complete the volume.

In general, the committee favors allocating the cost of service to both users and benefitted nonusers. Proportional rather than incremental cost is favored for fire protection, and demand ratio rather than proportional plant. A ready-to-serve or minimum charge to cover customer and part of capacity cost is recommended, together with three or more quantity blocks to cover the production and remaining capacity costs.

Chlorination of Sewage and Industrial Wastes. Manual of Practice No. 4. *Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill. (1951) $1.25*

A review of the history, development and current techniques of applying chlorine for treatment of waterborne wastes. The manual is the fourth of a series which includes "Occupational Hazards in the Operation of Sewage Works," "Utilization of Sewage Sludge as Fertilizer" and "Municipal Sewer Ordinances."

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BIG is the word for California—and among the biggest of its bignesses are its water works. What started with merely minor miracles such as the $25,000,000 Los Angeles Aqueduct and the $220,000,000 Colorado River Aqueduct has now really blossomed forth under the California Water Plan. Although we, here, know very little of the story, we've had enough of a squint at the plans of the Feather River Project and the Sacramento-San Joaquin Delta Diversion Projects, with their billion-plus price tag, to understand where Hollywood works up its adjectives. Meanwhile, of course, we can't forget the Central Valley project, which, over a period of twenty years, has made a desert bloom by—again—just adding water, through such "colossal" features as the second and fifth largest concrete dams in the world, hundreds of miles of canals and a river that flows upstream.

But what ho'd us westward in this mood originally was a follow-up on the 65,000-hp. pumps just put in service at Washington's Grand Coulee Dam. Not that Grand Coulee has been incorporated into California's water system (yet), but its "largest pumps in the world" are a product of California's Byron Jackson and Pelton Water Wheel companies. And doing things in the big way, Byjac bundled a dozen bigwigs into its private DC-3 and weekended them at the site of the $750,000,000 Columbia Basin plan. Whether or not Los Angeles' Mayor Fletcher Bowron, Caltech's Board Chairman Robert A. Millikan, California's State Engineer A. D. Edmonston or the other businessmen and engineers on the grand tour decided to *buy* wasn't revealed, but certainly Southern California's overall water problem is "big" enough to make them want to.

Long before the Grand Coulee item, though, we stuck out our New York neck to call "pie in the sky" the idea of atomic pumps pushing Columbia River water into Southern California. Now with 1-bgd. pumps on hand and with atom-powered planes and submarines just around the corner, we're not at all sure we won't be pulling back a bloody stump.

BIG, too, is the word for the California Section, which at this writing is poised just 14 short of the 1,000 mark in membership and which will undoubtedly go over the top during its annual meeting late this month. Not so much because we value our neck as because we don't want them to think our "pie in the sky" was made of sour grapes, we're jumping in now with our congratulations to the Californians among us for what we know they're going to do before these words reach them. One thousand not only strong but big—next thing you know they'll have more members than A.W.W.A.

Dowell Inc. has constructed a new building at 1150 N. Utica Ave., Tulsa, Okla., to house its offices, magnesium anode and chemical manufacturing plants, research laboratories and other facilities.

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Ellsworth W. Hudgens has joined the staff of Dowell Inc. as a development engineer specializing in cathodic protection.

W. H. Bolger has been appointed manager of laboratories of Robert W. Hunt Co., Engineers. Cromwell Bowen has been appointed assistant manager of laboratories.

Vernon R. Smith, manager of sales engineering for Metallizing Engineering, Inc., has resigned to devote his activities to the Stark Glass Co. of Massillon, Ohio.

Portable water mains are the newest thing in civil defense fire protection. Last August in New York City, the Fire Department required only 23 minutes to assemble 1,000 ft. of 8-in. pipe and 6 minutes more to start 3,015 gpm. of river water through it at a pressure of 225 psi. Laid by firemen under simulated emergency conditions from a docked fireboat to a point in the middle of Manhattan Island, the pipe proved itself capable of delivering river water at fire-fighting pressures to any spot in the city in a hurry. Made of spiral-welded cold-process steel, the pipe is of the same type as that used during World War II to fuel advancing armies from supply stations in the rear and as a substitute for air portage along 2,000 miles of the Burma Road. Mechanical couplings are used to make quick and easy jointing. Albert Pipe Supply Co. of Brooklyn provided the pipe and the Victaulic Co. of America, New York, the couplings used in the experiment.

If early enthusiasm turns out to be justified, it ought to communicate itself quickly to the water department, from whose shoulders and minds will be lifted one of the major problems of emergency water supply in wartime. And, inasmuch as tin cans have already made available portable potable supplies for use under disaster conditions, the water department ought to be almost dispensable during emergencies. Where's the nearest Shelter?

John B. Madden, formerly product supervisor, has been appointed hydraulic sales manager in the North Central Dist. for A. O. Smith Corp. His headquarters will be at 310 S. Michigan Ave., Chicago.

Robert B. Kitzmiller has been appointed manager of the San Francisco office of Rockwell Mfg. Co. He has been with the Rockwell organization since 1934.

Harold R. Fosnot has been appointed Eastern Sales Manager of Graver Water Conditioning Co., with headquarters at the company's home office in New York.

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Payment in kind seems suddenly to be causing a big fuss—and after all these years too. Anyway, when the Ottumwa, Iowa, local of the CIO Packinghouse Workers of America included among their demands of John Morrell & Co. free holiday hams twice a year for each employee, the idea created quite a stir on the nation's front pages. And it was big news, too, when a New Jersey contractor wrote into the specifications of a brewery construction job free beer for his workmen. Actually, with a ballooning dollar, it is little wonder that people are beginning to trust purchases more than purchasing power. But what we're worried about, of course, is how water is going to measure up as one of those extra additional job attractions. If we really relapsed into an overall economy of payment in kind, we'd probably get some W.C.T.U.'er to work for us, but, meanwhile, who?

Richard L. Lauderdale, Builders-Providence sales engineer, has joined the engineering sales staff of Builders-Pacific, Inc., at Berkeley, Calif.

A microfilm machine which can copy one or both sides of a document at a rate of 125 feet of paper per minute has been developed by Remington Rand Inc.

Service Lines

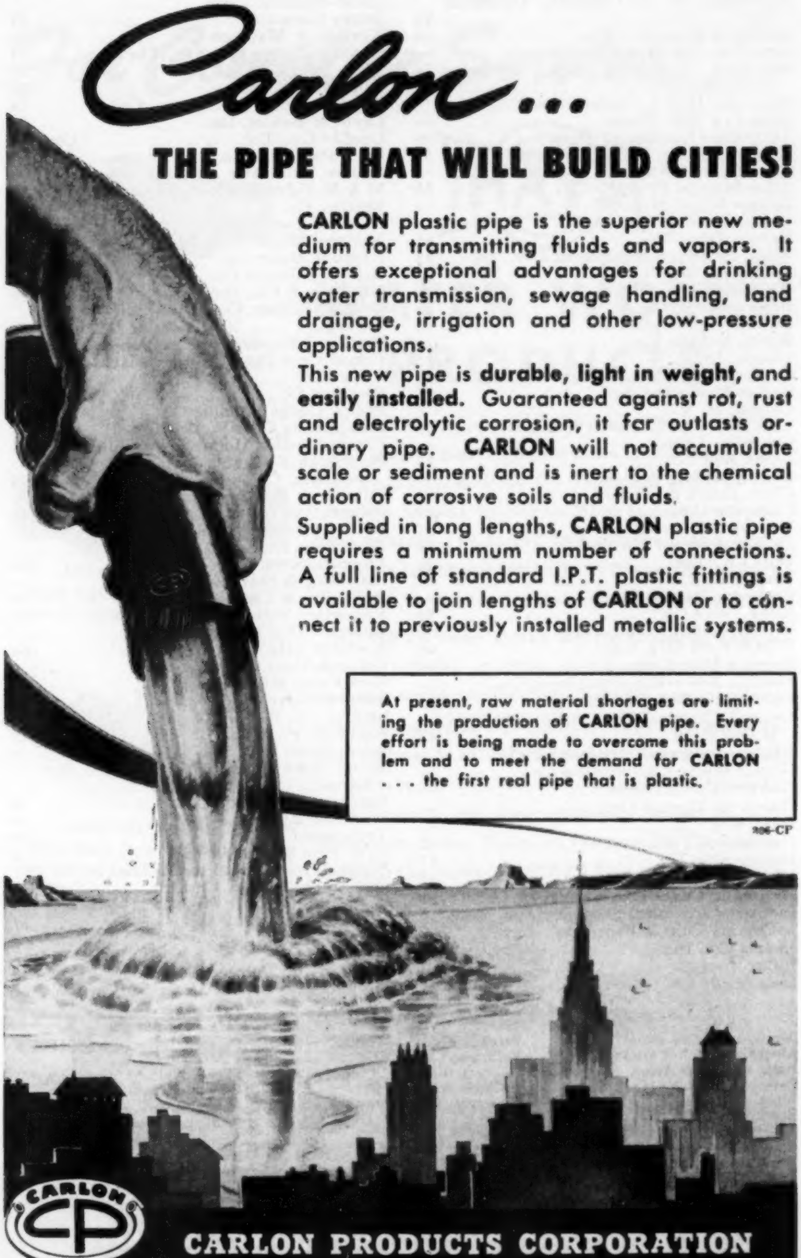
Selection of meters for measuring more than 200 liquids of varying corrosive characteristics is the subject of a bulletin, OG 400, "Industrial, Chemical and Refinery Meters" issued by Rockwell Mfg. Co., 400 N. Lexington Ave., Pittsburgh 8, Pa.

Milestones in the 50-year history of De Laval Steam Turbine Co. are featured in a 38-page commemorative brochure published by the company. Various products of the company—current and past—as well as typical shop operations are illustrated and discussed.

Total hardness determination studies have been listed in a bibliography on the analytical application of ethylenediamine tetraacetic acid. The 4-page mimeographed list is available without charge, together with literature on Sequestrene from Alrose Chemical Co., Box 1294, Providence 1, R.I.

Conveyor idlers and machinery are catalogued and described in a new 42-page bulletin, No. 51–81, issued by Chain Belt Co. of Milwaukee. Copies may be obtained from Dept. PR of the company, 1600 W. Bruce St., Milwaukee 4, Wis.

"Corrosion Resistance of Copper and Copper Alloys" contains the results of a quarter-century of studies conducted by the American Brass Co., Waterbury 20, Conn. Copies of the 24-page booklet, known as Anaconda Pub. B–36, are available on request. A tabulation giving the relative resistance to 183 corroding agents of various copper alloys is included.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